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COVER PICTURE

Overhead switchgear on a transmission line pylon in Pal Seco, Trinidad

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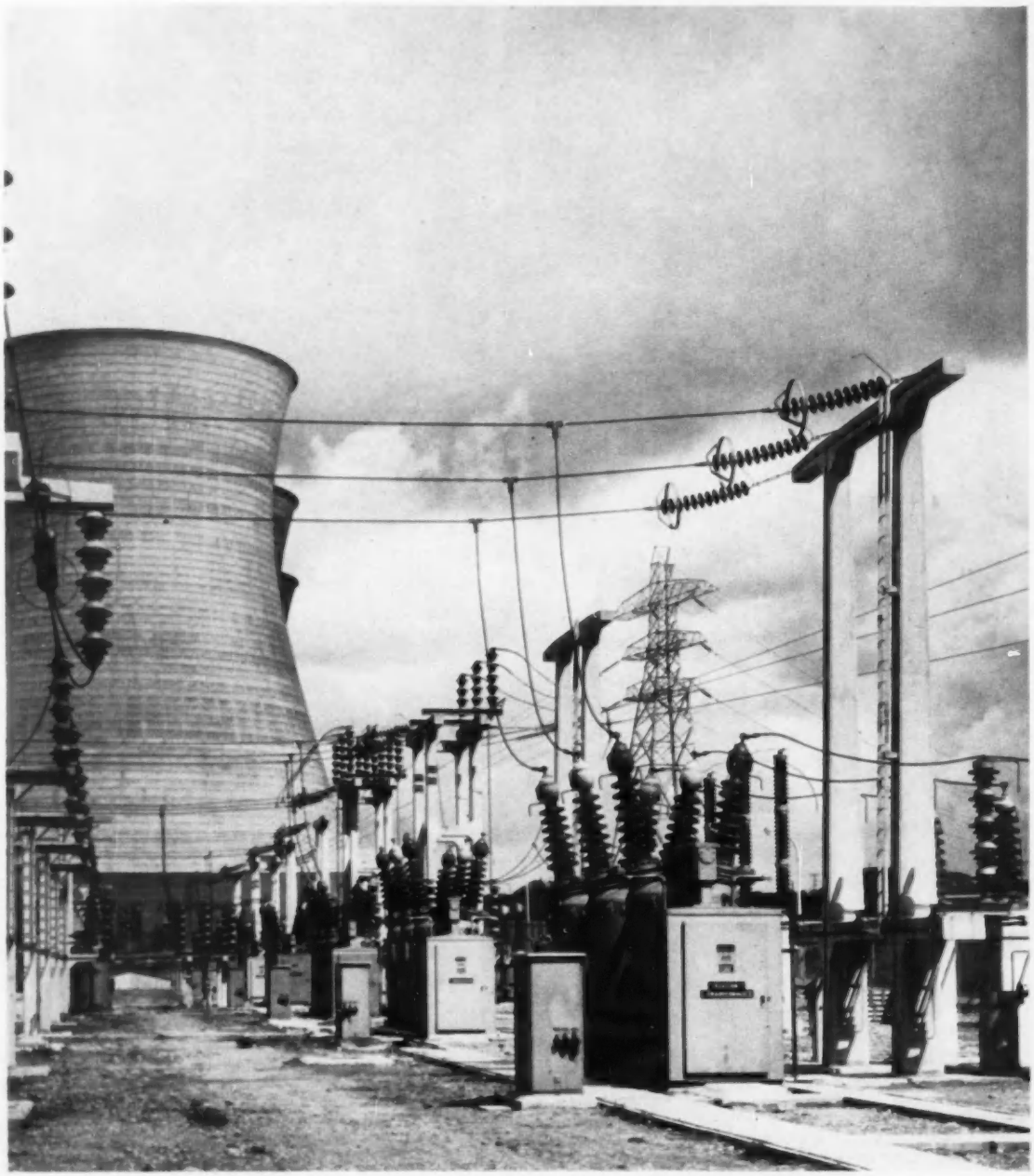

132 kV, 2,500 MVA outdoor oil circuit-breakers at Meaford 'B' Power Station.

A British Microwave Television Link in Canada

By A. D. HODGSON, M.I.E.E.,
Canadian General Electric Co. Ltd.
and G. M. B. WILLS, A.C.G.I., B.Sc. (Eng.), A.M.I.E.E.,
Telephone Works, Coventry.

DURING recent years the G.E.C. has supplied equipment for television links both to the British Post Office and to Overseas Administrations. These have included the link in East Anglia feeding the new transmitter at Norwich, the link between Birmingham and Lichfield, the cross-Channel link permitting the exchange of programmes between the B.B.C. and European television authorities, and the link across the Alps between Chasseral and Monte Generoso in Switzerland.

Although the equipment supplied for these links is basically similar, each system must be adapted to suit its location. For example, in planning a new link between London and Windsor, in the Province of Ontario, the fact that the countryside traversed is almost completely flat presented conditions entirely different from those of the link across the Swiss Alps, where one repeater station is at a height of 11,000 ft.

The London-Windsor link forms part of the Canadian inter-city television network, and was supplied to the Communication Departments of the Canadian National and the Canadian Pacific Railways. The Canadian General Electric Co. Ltd. (C.G.E.) was the main contractor, being responsible to the railway

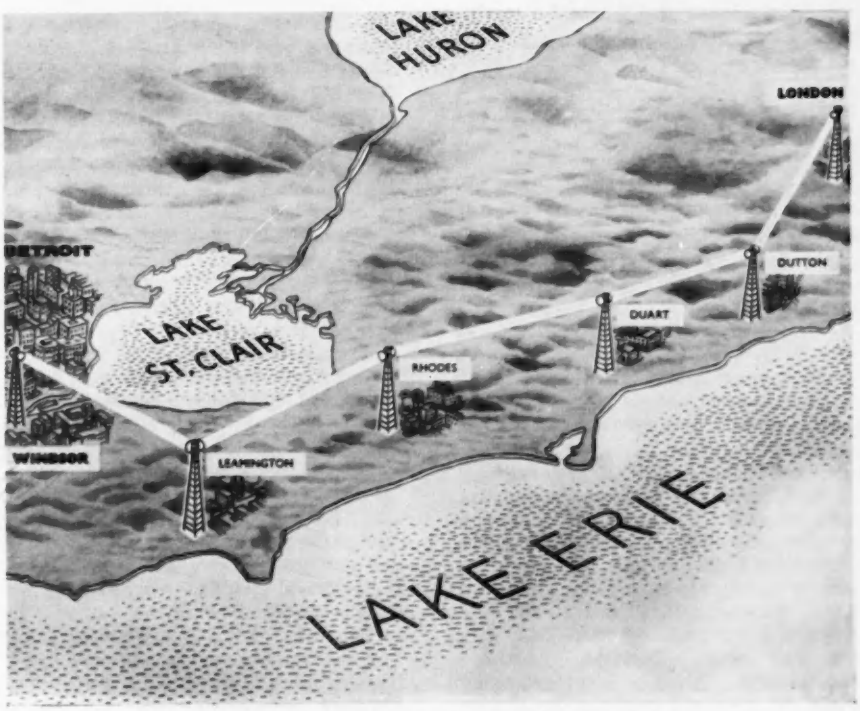

Fig. 1.—Route of the London-Windsor television link in Ontario.

administrations for handing over the complete system operating in accordance with the specifications which formed part of the contract. Thus, C.G.E. made the route surveys and subsequent selection of microwave-station sites and was responsible for the provision, installation and testing of the radio-relay equipment, the automatic standby power-supply equipment, the towers, the radio-feeder lines, aerials, etc.

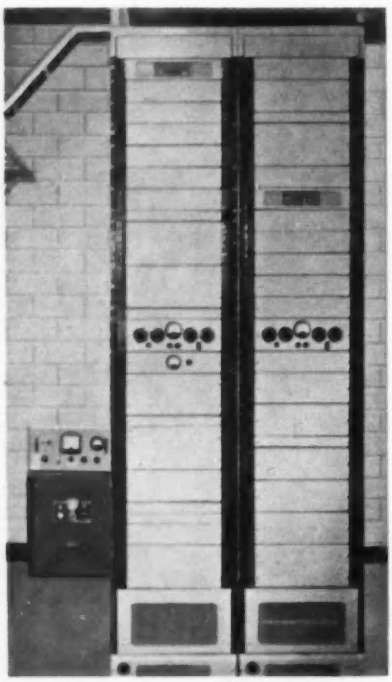

Fig. 2.—Radio equipment at the London terminal.

The G.E.C. Telephone Works, Coventry, acted as the subcontractor for the supply of the radio-relay, supervisory control, and testing equipment, and for the aerials.

Although the link is bordered on the south by Lake Erie and on the north, in part, by Lake St. Clair, the whole of the route passes over land (fig. 1). Only for a few miles at the London end is there any change from the flat countryside which is the most striking characteristic of the route.

When the detailed system-layout planning began, a tentative route had already been chosen, using five repeater stations between London and Windsor. A second route, using only four repeater stations, was selected from maps, and field surveys of both routes were then made in which tree heights and elevations were measured. System performance calculations were then made and the aerial sizes, tower heights, etc., determined for both routes. Since no appreciable improvement in performance would have resulted by using five repeater stations, the more economic plan was adopted.

The route selected is 120 miles long, the distances between the repeater stations at Dutton, Duart, Rhodes and Leamington varying from 18·1 to 26·4 miles. Due to the flatness of the area, the aerial towers are higher than would have been necessary in an average countryside where prominent points could have been used to site the towers. The towers vary from 151 to 234 feet in height.

First Fresnel Zone clearance, based on four-thirds true earth's radius, is provided on all five sections and free-space attenuation between aerials assumed to be the normal condition. Subsequent tests showed this assumption to be justified.

Since a high degree of reliability is required, and poor propagation conditions can be expected at certain times of the year owing to the nature and situation of the route, allowance has been made for a substantial fading margin. Because the transmitted frequency is repeated on alternate sections of the route in each direction of working, a receiver might, under abnormal conditions, receive signals from a more distant transmitter as well as from the one which it is intended to receive. This condition is known as " overshoot reception " and should not be confused with the transient phenomenon known as " overshoot ".

To protect the system against interference from this overshoot reception, the ratio of the wanted to the unwanted signal must be sufficiently large ; in general, at least 30 db, and preferably in excess of 40 db, even under adverse propagation conditions.

The section of the route most liable to problems of overshoot reception is that between Leamington and Dutton, where the line of the interfering path is 6° 47′ East of the line from Leamington to Rhodes and 5° 09′ West of the line from Dutton to Duart. In order to afford the maximum protection possible, the aerial polarisation layout was planned so that the interfering signal and the desired signal are in space quadrature.

In the abnormal circumstance that a free-space path exists for both the desired and the interfering signal, it was calculated that, taking into account the directional properties of the aerials, the interfering signal would be attenuated by at least 65 db more than the desired signal ; this attenuation gives adequate protection. It is conceivable that, under very abnormal conditions, the desired signal may fade while a free-space path exists for the interfering signal. When such a fade is 22 db, adequate protection still exists since the level of the received interfering signal is at least 43 db below that of the desired signal.

The radio equipment supplied is SPO.5551, which operates on an unattended basis in the 1,700 to 2,300 Mc/s frequency band. The London-Windsor equipment transmits 525-line television waveforms, and provides two one-way reversible television channels. It is complete with supervisory control and alarm systems.

A technical summary of the equipment (adjusted for 525-line signals) is given below :

Type of modulation ...	Frequency
Transmitted frequencies	Within the 1,700 to 2,300 Mc/s band

Transmitter output power	Approximately 2 watts.
Aerial gain	32 db each aerial.
Transmitter deviation...	6 Mc/s peak-to-peak
Baseband width (for above deviation)	Greater than 4·5 Mc/s
Receiver noise factor ...	15 db
Receiver bandwidth ...	16 Mc/s
Frequency stability ...	Better than 1 part in 10^4 (independent of length of system)

TERMINAL TRANSMITTER.

The terminal transmitter is contained on two racks, which may be mounted either side by side or back to back. Fig. 2 shows the terminal transmitter equipment at the London terminal. The incoming video signal is amplified and D.C. restored in the input-monitoring panel before passing to the frequency-modulator stage. Automatic frequency control ensures that the frequency corresponding to the bottom of the synchronising pulses is within the correct range for the equipment.

The frequency-modulated signal, with a mean frequency of 60 Mc/s, is passed through a wideband filter and applied to a high-level frequency changer. By suitably choosing the frequency of the U.H.F. carrier drive, one sideband of the frequency-changing process is made to coincide with the frequency band it is desired to transmit. This sideband is selected by a U.H.F. bandpass filter and passes through three stages of R.F. amplification and a U.H.F. changeover switch to the aerial-feeder system.

A disc-sealed triode is used in the U.H.F. circuits. It is mounted in coaxial-line circuits using quarter-wave anode-grid lines and three-quarter-wave grid-cathode lines tuned by non-contacting bridges.

Automatic frequency control with a pull-in range of about 10 Mc/s is provided on the U.H.F. carrier-drive oscillator. The control operates if the frequency difference between the oscillator and its reference cavity exceeds 60 kc/s.

The final stage of U.H.F. amplification takes place in two 1-watt amplifiers.

TERMINAL RECEIVER.

Two racks are also used to house the terminal receiver, which is of the single-superheterodyne type. A bandpass filter selects the wanted signal from the incoming signal, and passes it to the receiving mixer, which uses a silicon crystal. The output of a local oscillator of the same type as that used in the transmitter to provide the carrier drive is mixed with the signal to produce an intermediate-frequency band centred on 60 Mc/s.

After amplification in a low-noise I.F. pre-amplifier, and again in the main I.F. amplifier, the signal is fed to the television demodulator. Automatic gain control is applied at both amplifier stages.

The demodulator, which incorporates wideband amplifying and limiting stages, feeds a discriminator of the two tuned-circuits type, each circuit being driven by a separate amplifier. The video output from the discriminator is amplified in a multi-stage amplifier, in which the D.C. component of the signal is restored.

REVERSIBLE REPEATER.

The repeater equipment is also mounted on two racks. Fig. 3 shows the installation at Rhodes repeater station, where the racks are mounted back to back. The signals are not demodulated to baseband ; the connection between transmitter and receiver is made at the intermediate frequency of 60 Mc/s. The circuits of the repeater are similar to the R.F. and I.F. circuits of the terminal transmitter and receiver.

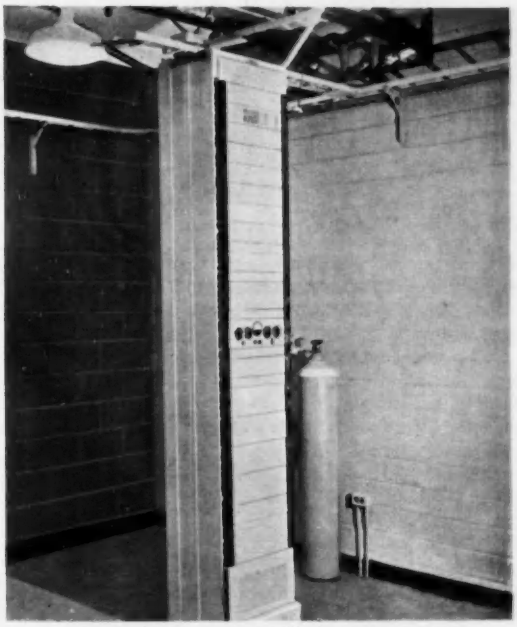

Fig. 3.—Radio equipment at Rhodes repeater station.

The frequency stability of the outgoing signal depends only on that of the incoming signal, and of the shift-frequency generator, which employs a crystal-controlled oscillator. Any drift in the U.H.F. oscillator frequency at a repeater is cancelled before retransmission. A frequency shift of 72 Mc/s is used at repeaters.

U.H.F. SWITCHING.

The U.H.F. switch, fig. 4, comprises a coaxial-line ring with four equidistantly spaced outlets. Each section of line between the outlets has two stubs, which are either open-circuited or short-circuited by a non-contact bridge, according to the position of a motor-driven cam ; alternate sections of the coaxial-line ring are arranged to become paths of high and low attenuation respectively. The switch is used to reverse the

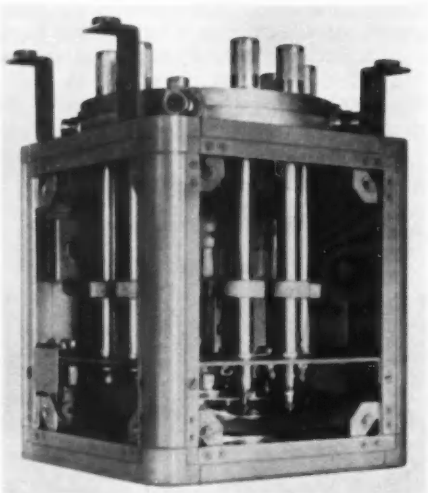

Fig. 4.—U.H.F. changeover switch for reversing the operation of a repeater station.

direction of operation at a repeater, and to connect either the transmitter or receiver to the aerial at a terminal.

The non-contact short-circuit is obtained by the introduction of a series-resonant circuit across the free ends of the stub. The voltage standing-wave ratio of an arm of the switch in the *pass* condition is better than 1·25:1 over a 30 Mc/s band; and in the *stop* condition the attenuation in the same band is greater than 60 db.

MECHANICAL CONSTRUCTION.

The racks are 9 ft. high, 1 ft. 8½ in. wide and 8½ in. deep, and may be mounted either side by side or back to back since access is required only from the front. They are constructed of folded steel with welded joints. Panels housing the equipment slide into guides fitted on the inside edges of the rack. They are secured by screws and fitted with dust covers flush with the front of the rack.

Connections are made between the panels and rack by bridging plugs, which also serve as test points. Intermediate-frequency and radio-frequency connections are made with coaxial cables or U links. A panel may be removed, after the connecting plugs have been taken out and the R.F. connections disconnected, and bolted to the rack back to front for maintenance purposes (fig. 5). Test cords are used to make the connections to the rack cabling.

AERIALS AND FEEDERS.

The aerials consist of 12-ft. diameter spun-aluminium paraboloids of revolution, excited by waveguide launching units located at the focus. The launching unit provides for vertical and horizontal polarisation (fig. 6), so that vertical polarisation can be used for one of the two reversible links comprising the system and horizontal polarisation for the other.

Rigid coaxial transmission line, 1·625 in. in diameter and of 50-ohms characteristic impedance, is used for the main feeds up the towers. The connections to the aerials are made by tails of 0·735 in. diameter helical-membrane semi-flexible cable of 75-ohms impedance, which is connected to the horizontal and vertical probes on the launching unit.

The transmission lines are fed into the equipment rooms at the bases of the towers, and connected to points on both sides of the U.H.F. switches by short tails of solid dielectric flexible cable of 62-ohms impedance, similar to the internal R.F. cabling in the equipment racks. Transformers at the two ends of the transmission lines effect impedance and size transformation.

The transmission lines, semi-flexible cables, and launching units are filled with dry air at a pressure of about 3 lb. per sq. in., the mica window at the front of the aerial-launching unit forming the air-seal at the aerial end. Pressure is maintained automatically by a small electric motor-driven pump. The air is passed over a silica-gel desiccator, which is dried automatically by a heater unit at regular intervals.

Fig. 5.—Panel withdrawn and bolted back to front to rack for maintenance.

TOWERS.

The self-supporting steel-lattice towers, carrying the two aerials at repeater stations and one at the terminal stations, have been designed to allow the installation of duplicate sets of aerials if extensions to the system are required. At the London terminal the aerial was mounted on an existing tower of the London-Toronto microwave system.

Fig. 6.—An engineer working some 200 ft. above the ground on the launching unit of a repeater station aerial.

The towers are fitted with aircraft warning lights and painted orange and white to conform with current Canadian regulations. Fig. 7 shows the aerials and tower at Dutton repeater station and fig. 11 the Windsor tower and aerial.

POWER SUPPLY.

Power plant of the " no-break " diesel-alternator-motor type is installed at the repeater stations (fig. 8). The radio equipment is fed from the three-phase alternator driven by the wound-rotor induction motor. The alternator runs on the same shaft as a large flywheel and a clutch connects the shaft to the diesel engine. The diesel starts up immediately the mains supply fails. When the diesel has reached the correct operating speed, it takes over the load through the clutch, the flywheel taking the load during the interim period.

The standby equipment has a capacity large enough to provide sufficient power when new extensions to the radio system are made.

SUPERVISORY CONTROL EQUIPMENT.

Supervisory control and alarm equipment provides remote control of all stations from the Control Point in Windsor, and caters for future extensions to the system. It operates over one pair of wires on an open-wire pele route provided by the Railway Administrations. The connections between the Windsor terminal and the Control Point, which is remote from the terminal, are effected over cable pairs.

At the Control Point there is a continuous display for each station of a number of functions associated with the radio equipment, the auxiliary equipment, and certain other features such as the fire alarms and aircraft-warning lights. The display is effected by the use of discrepancy keys, each one showing the condition (on, off, etc.) of the function with which it is associated. If the condition of a piece of equipment in a station changes so that it no longer corresponds with the position of the key at the Control Point, a lamp associated with the key flashes and an alarm sounds until the attendant has altered the position of the key to correspond to the new conditions. In this way a continuous indication of all functions at every station is given, using a minimum amount of power and ensuring maximum lamp life.

Most control functions, such as reversing the direction of working, are performed at all stations simultaneously: but others are controlled individually,

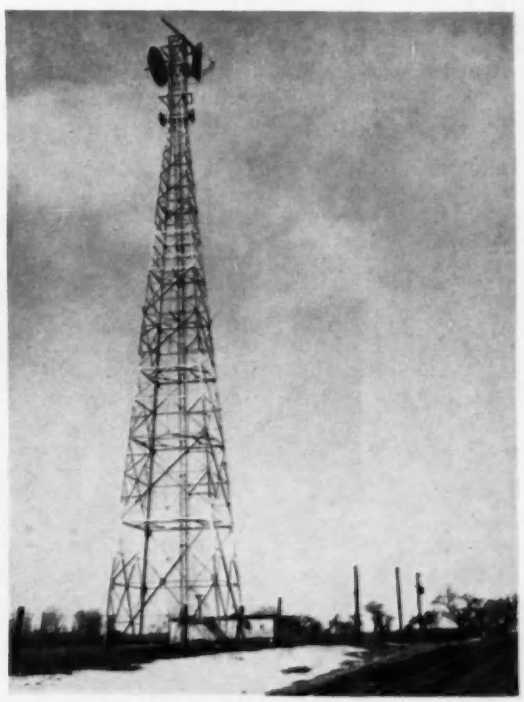

Fig. 7.—Aerials and tower at Dutton repeater station.

for example, switching on the standby power supply for test purposes. Every station has a local display panel which duplicates its remote display at the Control Point. This panel can be switched on by a visiting maintenance man, who can also take over control of the station from the Control Point.

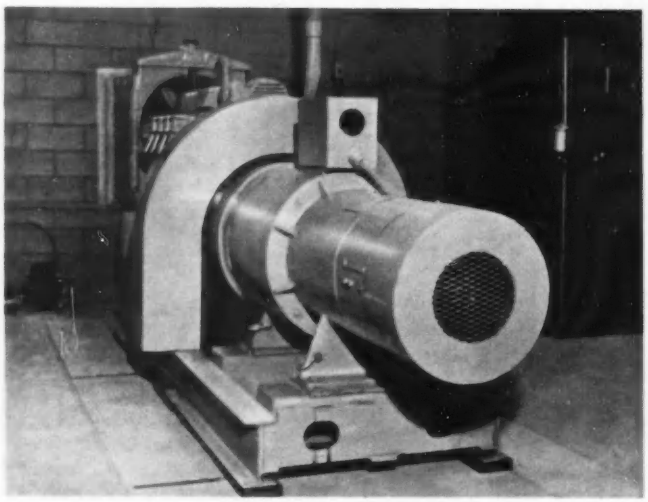

Fig. 8.—Diesel-alternator-motor power plant.

Whenever the condition of a function changes at a remote station, a train of impulses is sent to the Control Point. This train always contains the same number of impulses, one for every function to be reported, but the length of an impulse depends on the condition of its associated functions. For example, should the power monitor on the transmitter in the East-West direction on Link I at Rhodes repeater station indicate a low output from that transmitter, a complete train of impulses would be sent from Rhodes to the Windsor Control Point. All impulses would have the same length as the last time they were sent except that corresponding to the power monitor, which would be long instead of short. The lamp associated with the key labelled RHODES E-W TRANSMITTER LINK 1 would then flash until the attendant changed the key position from "Normal" to "Low".

Codes of long and short impulses are also used to start control functions. When a control is to be effected, one or more locking select keys are operated and a common transmit key is pressed. This results in transmission of a signal code consisting of twelve impulses, any one of which may be long or short.

Lamps are used to give failure warnings from the voice-frequency telegraph equipment, which is of the frequency-shift type and can give an alarm in case of a line break, or a failure of the distant equipment.

Fig. 9.—An aerial being prepared before erection at Rhodes repeater station.

INSTALLATION AND TESTING.

The system was supplied and installed in three stages. First a one-way television channel working from London to Windsor was completed, then a second reversible one-way television channel was installed, and finally the first channel was converted to be reversible, and the supervisory control and alarm equipment was provided. Fig. 9 shows an aerial being prepared prior to hoisting up the tower at Rhodes repeater station.

The racks and panels were supplied separately packed. This greatly facilitated transport and handling of the racks during erection. After the racks were mounted in position the inter-rack and power cabling was connected, and the panels slid into their appropriate positions. Finally, the plugs and U-links were inserted to connect the panels to the racks.

The testing of each stage of the system was carried out in three parts. First the local tests were conducted at individual repeater and terminal stations (fig. 10), then interstation tests were carried out between adjacent stations, and finally a series of through tests was conducted between the terminals at London and Windsor. Tests carried out on the system gave results that differed very little from the theoretical figures calculated during planning.

Fig. 11.—Aerial tower at Windsor, with Detroit in background.

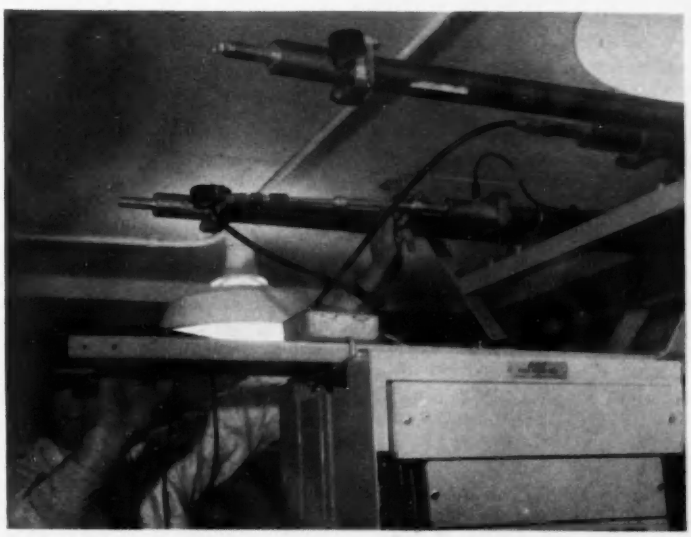

Fig. 10.—Adjusting attenuation at receiver input preparatory to calibration of fade recorder at Leamington repeater station.

Electron Diffraction

Its Application to Chemical Analysis

By B. S. COOPER, B.Sc., F.INST.P., and H. E. BULLEN, B.Sc.,
Research Laboratories.

Electron diffraction and X-ray diffraction are in general complementary, each having outstanding advantages in a number of distinct fields of application. An electron diffraction camera is described, and notes on the preparation and handling of specimens define the types of sample suitable for examination by transmission and by reflection. Notes on the types of diffraction pattern and their interpretation are followed by examples of applications of the method to particular problems in which it is able to support the analytical facilities of a large industrial organisation.

INTRODUCTION.

THE great majority of chemical substances are possessed of regular crystal structure, i.e. the various constituent atoms of the substance are arranged in space in an ordered manner. This regularity of structure leads to diffraction effects when electro-magnetic radiation of appropriate wavelength, such as X-rays, is incident upon a sample of the substance, and this phenomenon is the basis of one of the most useful and versatile methods for the identification of chemical compounds. The technique and applications of X-ray diffraction have already been described in detail in this journal,* while the relationship between X-ray diffraction and other important analytical methods has also received consideration.†

Another approach to the investigation of crystalline materials became possible with the experimental realisation of the fact that electrons have some of the properties of waves, the wavelength being inversely proportional to the momentum of the electrons. Although it was as recently as 1927 that the pioneer experiments of Davison and Germer in the U.S.A., and Thomson and Reid in this country, presented the first experimental evidence of the diffraction of electrons by metal specimens, the technique is now in everyday use in many laboratories and is a valuable addition to existing methods of determining the structure and composition of materials of technical importance.

SCOPE OF THE METHOD.

Electron diffraction should not be considered as a technique which may be used as an alternative to X-ray diffraction. It is true that analytical problems do arise from time to time to which either method could be applied with almost equal chance of success in order to identify an unknown substance but, in general, the two methods are complementary in that each has a number of distinct fields of application for which it has outstanding advantages. There are, in fact, certain types of problem in which the electron diffraction method is the only way of obtaining the required information. These problems will be discussed in greater detail later but broadly they are problems in which the constitution of surfaces and of thin films is of paramount importance. Any analytical research team working in these fields will find an electron diffraction section a most valuable addition to its facilities.

Previous experience with X-ray diffraction is a great advantage when undertaking electron diffraction studies since the procedure in interpreting the diffraction patterns is very similar for both techniques. On the apparatus and experimental side, however, there are considerable differences between the two methods ; in fact, an electron diffraction camera has far more affinity with an electron microscope than with an X-ray diffraction apparatus.

The important point to appreciate, when comparing electron diffraction and X-ray diffraction, is that electrons, even at the highest velocities practicable, are scattered and absorbed far more readily than are X-rays. Electrons accelerated through 40 to 60 kV, the normal working voltage of modern diffraction cameras, will not, in fact, penetrate more than about 10^{-5} cm. of matter at normal incidence. If the incident beam is directed on to the surface of a sample at an angle of only about 2°, which frequently occurs in practice, then the electrons will penetrate less than 50 Angstrom units (1 A.U. = 10^{-8} cm.) below the sample surface. This depth is equivalent to only 20 to 30 lattice planes in the average material. It is this very small depth of penetration which makes the electron beam such an outstanding tool for the investigation of surface phenomena.

A further practical consequence of the ease with which electrons are scattered by matter is the requirement that the examination be carried out *in vacuo*, as also applies with the electron microscope. While it is certainly an inconvenience to carry out the necessary

* *G.E.C. Journal*, Vol. XI, No. 2, pp. 83-95, August, 1940.
† *G.E.C. Journal*, Vol. XVII, No. 4, pp. 207-216, October, 1950.

experimental manipulation *in vacuo*, modern equipment and techniques have been improved so much that a properly designed diffraction apparatus is a relatively speedy and convenient tool to operate.

From this discussion it will be clear that certain necessary conditions need to be fulfilled in order that a useful electron diffraction pattern shall be obtained from a sample. These are :

(1) The sample of interest shall have sufficient regularity of structure (crystallinity) to exhibit diffraction effects with fast electrons.

(2) The sample of interest must be in the form of :
  (*i*) A thin film of material (not more than 10^{-5} cm. thick).
  (*ii*) A fine powder (suitably dispersed in an electron transparent membrane).
  (*iii*) The immediate surface of a massive specimen.

(3) The sample must be stable *in vacuo* and under electron bombardment.

At first glance it may appear that these several restrictions limit the usefulness of the method to a very narrow field of investigation, but a little consideration will show that it is in this field that one may expect to obtain valuable information regarding many problems of technical importance. A representative, but not exhaustive, list would include such studies as : oxidation and corrosion of metals and alloys ; formation of protective surface coatings ; grinding and polishing of surfaces ; lubrication ; surface of chemical catalysts ; rectifying contacts, and so on.

THE ELECTRON DIFFRACTION CAMERA.

The electron diffraction camera in its simplest form consists of some means for producing a beam of electrons of uniform and constant velocity, a device for holding the specimen under examination and manipulating it, a fluorescent screen for observing the diffraction pattern, and a photographic camera for obtaining the permanent record. These separate features are all enclosed in a chamber which is capable of being evacuated down to a pressure of 10^{-4} millimetres of mercury.

Fig. 1 shows diagrammatically the essential features

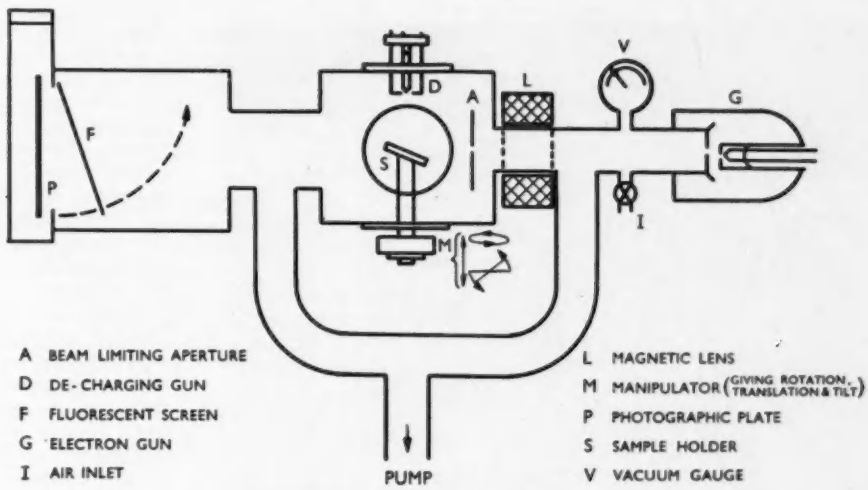

Fig. 1.—Diagram of electron diffraction camera.

of the electron diffraction camera which was designed and built at the G.E.C. Research Laboratories. The optic axis of this particular design is horizontal, the electron beam being generated in the electron gun *G* at the right of the diagram, while the photographic plate *P*, on which the diffraction pattern is recorded, is in the chamber at the extreme left of the assembly.

The electron gun *G* is of fairly conventional design, although considerably more complicated in construction than is suggested by the simplified sketch in fig. 1. The electrons are emitted by a pure tungsten filament operating at relatively high temperature, this form of unactivated cathode being essential in an apparatus which is alternately evacuated and opened to air as part of the normal operating procedure. The electrons are accelerated by a potential difference of 50 kV between cathode and anode, the beam emerging through an axial aperture in the anode. This high voltage is supplied by a stabilised circuit designed to hold the voltage constant to better than one part in a thousand ; this ensures that the electrons in the beam have sensibly constant velocity and thus constant wavelength, i.e. the beam is monochromatic.

The magnetic lens *L* consists of a coil of about 13,500 turns of 36 gauge copper wire mounted axially outside the vacuum chamber. When the lens is energised by a

current of approximately 25 mA, the electron beam is brought to a fine spot focus in the plane of the photographic plate *P* at the other end of the apparatus. The total distance traversed by the electron beam from gun to photographic plate is about 100 cm.

The enlarged section immediately to the left of the magnetic lens is the specimen chamber. This is constructed with four access ports in order to obtain the greatest degree of versatility with the apparatus. As shown in the diagram, the bottom port is occupied by the specimen holder *S* which is operated by the manipulator *M*. This manipulator enables the specimen to be given movements, *through vacuum-tight seals*, of rotation, tilt or translation. The movements of the mounted specimen may be viewed through a window in one of the ports at right angles to the one occupied by the specimen manipulator.

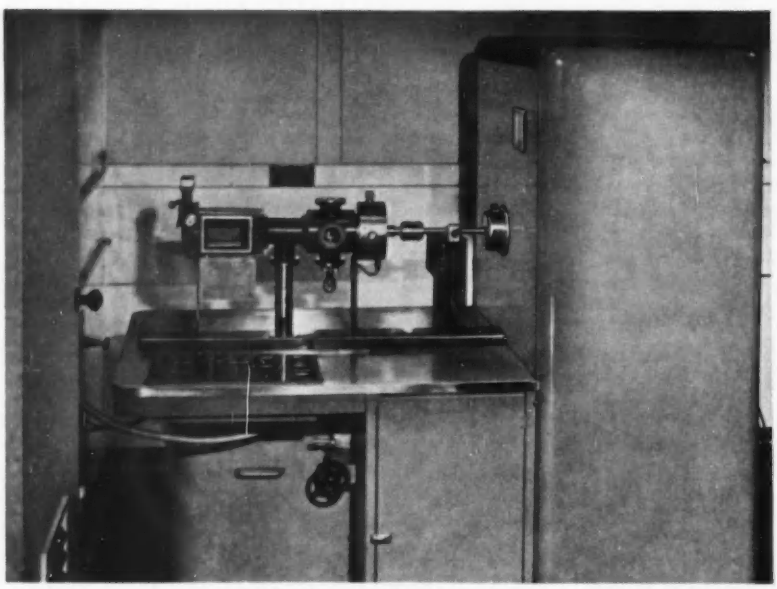

Fig. 2.—Electron diffraction apparatus.

Other ports in the chamber may be occupied by further accessory apparatus essential to the particular investigation. A third port is almost invariably occupied by another manipulator designed to insert or remove a beam-limiting aperture (*A* in the diagram). The top port is shown occupied by a subsidiary electron gun *D*, used as an aid to dissipating the charge on samples of an insulating nature, which acquire electric charge when the main electron beam is incident on them. Other useful accessories which may be fitted into one of these access ports are electrical leads to a small furnace for heating samples *in situ*, or entry and exit tubes for introducing a special atmosphere for treatment of the sample between successive electron diffraction examinations.

Finally, the viewing chamber at the left hand end of the apparatus is equipped with large windows on each side through which the electron diffraction pattern may be observed on the fluorescent screen *F*. When a photographic record is required, the viewing windows are covered with light-tight shutters and the photographic plate is exposed by raising the fluorescent screen, which is hinged so as to serve also as a photographic shutter.

This completes mention of the principal components which make up the electron diffraction camera proper. Many minor features, which are essential to satisfactory operation of the equipment, are also incorporated but need not be described in any detail. For example, provision must be made for controlled lateral movements of the electron gun and of the magnetic lens in order to obtain satisfactory alignment of the system. Extra diaphragms, not shown in the sketch, are incorporated in order to trap scattered electrons arising from the incidence of the main electron beam on the edge regions of restricting apertures. A readily removable section of "column" is also provided in order to obtain ready access to those parts of the interior equipment which need periodical inspection and cleaning.

Before leaving the instrument mention must be made of the two important services—electrical and vacuum. These are integral with the equipment and need to be of the highest order of excellence for their purpose. For the electrical supplies, power is taken from the normal 240-volt, 50-cycle supply mains and fed to appropriate electronic circuits which provide for the following electrical requirements :

(*a*) A stabilised 50 kV supply for the electron gun.
(*b*) Gun filament heating current (this is supplied to the filament, which is held at −50 kV with respect to earth).
(*c*) Gun cathode shield bias voltage.
(*d*) Lens current supply (40 mA stabilised).
(*e*) Anode voltage and filament supplies for the decharger gun.

As mentioned earlier, the 50 kV supply for the main electron gun must be controlled to better than one part in a thousand in order that the electron beam shall be sensibly monochromatic. Another supply which must be stabilised is the lens current, which must be kept constant in order that the focal length of the magnetic lens shall be of constant value.

The working pressure in the apparatus must be kept at about 10^{-4} mm. of mercury. Insertion of specimens and the changing of photographic plates involves, on each occasion, admission of air to the system. To ensure reasonable speed of working it is thus essential to have a fast pumping system, both for exhausting the relatively large chambers of the apparatus in as short a time as possible and for maintaining the vacuum against the inevitable leaks that occur in a multi-jointed system of this type. As a matter of interest there are over twenty joints in the complete assembly, nearly half of which must be sufficiently "free" to be either broken and remade frequently during normal operation or to act as seals on transmitted motions. It is owing to the excellence of modern pumping equipment and accessories such as vacuum seals that the use of sealing wax and greases—at one time the "trade mark" of vacuum physics research equipment—has largely disappeared.

A photograph of the complete apparatus is shown in fig. 2. Some of the major features of the camera proper, such as the viewing chamber, specimen chamber and manipulator, and magnetic lens, may be identified from the diagrammatic sketch of fig. 1. The electron gun, however, is inside the large rectangular cabinet on the right of the apparatus in order that all the high-voltage connections can be kept within a protected enclosure. For convenience all the other electrical circuitry is also housed in this cabinet. The pumps are mounted below the main table and are accessible through doors, one of which can be seen in the photograph.

An instrument and control panel is mounted flush in the table top; this contains switches and adjustments for the various circuits which control the main electron beam, the magnetic lens and the decharger gun and other accessories. A clock is also included on the panel for timing the photographic exposures. The instrument panel is conveniently placed so as to be kept under observation by an operator who is using the specimen manipulator and observing diffraction patterns on the fluorescent screen.

The apparatus is housed in a small room, about 10 ft. square, partitioned off from a larger laboratory. This is a convenient arrangement since it is often necessary for the operator to make visual observations in subdued light or near darkness.

Large double doors (open in fig. 2) are, however, provided so that ready access to the apparatus may be obtained for purposes of demonstration or servicing. Sample preparation and inspection of diffraction photographs are carried out in the adjacent laboratory.

PREPARATION AND HANDLING OF SPECIMENS.

As already mentioned, those problems of chemical constitution most appropriately investigated by electron diffraction concern samples either in an extremely fine state of subdivision or in the form of thin films or surface layers. Samples thus usually occur in one of two distinct classes and this dictates the manner in which they are mounted relative to the direction of incidence of the electron beam.

(*a*) SAMPLES SUITABLE FOR EXAMINATION BY TRANSMISSION.

When samples occur as small particles of dimensions comparable with, or less than, the wavelength of visible light, i.e. principal dimensions of 0·001 mm. or less, a preparation may be made in which the particles are dispersed and held in a thin film of material which is itself relatively structureless and transparent to the electron beam. Films of nitrocellulose and of certain other organic substances are suitable for this purpose. The sample under test is dispersed and deposited on the organic film, or it may even be incorporated in the organic substance at a stage prior to the making of the film, which is then transferred to a specimen holder. This usually consists of a small disc of fine metal gauze, 2 to 3 mm. in diameter, which supports the organic film at a number of points of contact but leaves several apertures available through which the electron beam may pass. The gauze is held firmly in a suitable mount on the sample holder of the diffraction camera, so that the organic film containing the sample is vertical, i.e. perpendicular to the axis of the electron beam.

Under these conditions, provided the particles of sample are crystalline in character, part of the incident electron energy will be deviated through certain specific angles as a result of diffraction by the lattice planes of the crystalline particles. The resulting diffraction pattern, as observed on the fluorescent screen or photographic plate, is produced by the incidence thereon of the undiffracted beam and the various diffracted beams of electrons. In general, each crystalline sample will produce its own characteristic diffraction pattern.

Other types of specimen which can also be examined by this "transmission" technique are thin films formed by evaporation and deposition *in vacuo*, and thin cleavage slices from single crystals.

(*b*) SAMPLES SUITABLE FOR EXAMINATION BY REFLECTION.

Very many problems of technical and industrial importance are concerned with the nature and constitution of samples which occur as surface layers on substances sufficiently thick to be quite opaque to the electron beam. Such surface layers are not always readily removable for the purpose of being made into "transmission specimens"; in fact, it is often desirable or even essential that they should be examined *in situ* on their parent substrate. Examples in this class are: the immediate surfaces of worked or polished materials; oxidation or other corrosion products on the surfaces of metals; surface compounds formed by heat treatment; films deposited on components during the operation of electric lamps, radio valves, X-ray tubes, etc.; protective finishes.

Fortunately, diffraction patterns can be obtained from the surface layers of such specimens by allowing the beam of electrons to strike the specimen at grazing incidence, in practice often at an angle of about 1° or less. Although usually referred to as "reflection patterns," the process is much more in the character of transmission than of reflection; the electrons are considered to pass through excrescences on the surface

under examination and thus undergo diffraction. As mentioned at the beginning of this article, it is only necessary to postulate excrescences of 20 or 30 atomic diameters in order to provide sufficient " roughness " for electrons to be diffracted by transmission. The resulting patterns are thus very similar to the normal

Fig. 3.—Mounting the sample prior to insertion in the camera.

transmission patterns but differ in that part of the pattern is missing where the " shadow " of the bulk of the specimen occupies the viewing screen. The individual diffracted rays are also slightly more diffuse than in the true transmission pattern, since the specimen-to-plate distance (which controls the position of a diffracted ray on the screen) is less well defined at grazing incidence.

Typical results of patterns obtained by these two methods of specimen mounting will be illustrated later. All that need be said in concluding these remarks on specimen preparation is that, because the method is so sensitive, contamination of the surface of samples must be minimised at all costs. The surface to be examined should not be touched by any extraneous material which might leave the faintest suggestion of surface contamination. For this reason the reflection type of specimen mounting is usually to be preferred since no " specimen preparation " is involved and touching the specimen with tools or reagents can be avoided.

Having prepared the specimen, it is suitably mounted on the small table attached to the specimen manipulator and inserted in the apparatus (fig. 3). The camera is pumped out, the circuits energised to produce the electron beam and the specimen adjusted in position until the best diffraction pattern is observed on the fluorescent screen. When this condition has been achieved the pattern is photographed ; this usually involves an exposure of only a few seconds.

TYPES OF DIFFRACTION PATTERN AND THEIR INTERPRETATION.

Where the sample consists of a large number of very small crystals randomly orientated with respect to the electron beam, a pattern of continuous rings is obtained, each ring corresponding to diffraction at a particular crystallographic plane in the crystals. Typical ring patterns are shown in fig. 4 and 5 (a), the former being obtained by the transmission method of specimen mounting, while the latter derives from a reflection specimen, the shadow of which obscures the lower part of the pattern.

When the sample consists of fewer individual crystals, there may be insufficient individual diffracted beams to make up continuous rings and a pattern of " spotty " rings results. With reflection type specimens in the form of a continuous layer, the presence of fewer crystals in the path of the electron beam implies that the individual crystals are larger ; it is therefore of value in comparing two samples which are identical chemically to note whether there are differences in the degree of spottiness of the rings, indicating some measure of difference in crystal growth of the two samples. A pattern of this type is shown in fig. 5(b).

A further variation of the ring pattern sometimes occurs in which the rings are of stronger intensity at

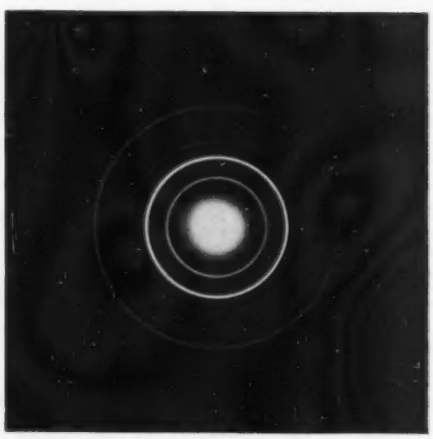

Fig. 4.—Ring pattern obtained by the transmission method (thallium chloride).

certain positions on their circumference, or may each consist of a number of short concentric arcs. This type of pattern indicates that the crystals in the sample are not arranged randomly but possess some degree of preferred orientation. An example is shown in fig. 6.

With progressively smaller crystal size, the rings become more diffuse and finally, with amorphous materials, no characteristic pattern occurs.

With single crystals the electron diffraction pattern usually consists of a number of spots, sometimes accompanied by pairs of parallel lines. These patterns are mainly of value in determining the orientation of the single crystal and are much less often of value for identifying the crystal. A typical example is shown in fig. 7.

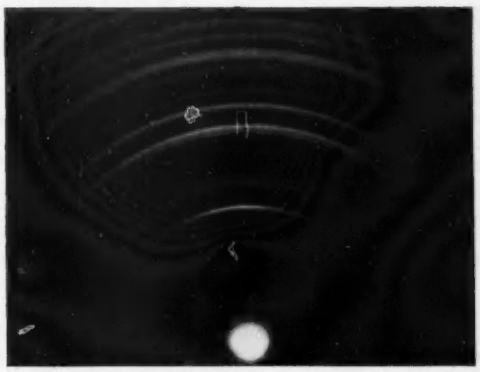

Fig. 5a.—Ring pattern obtained by the reflection method (nickel oxide).

A number of special types of pattern, not included in any of the foregoing descriptions, may also occur with particular samples. For example, the surface of a polished metal gives a pattern different from that of the underlying unworked material; such a pattern is typical of a "polish layer." Another characteristic group of patterns is obtained from thin films of organic materials such as oils and greases.

The interpretation of patterns is, in general, based on the procedure already well established in X-ray diffraction work, ring patterns being the most readily interpreted. The procedure involves a careful measurement of the diameters of the various rings, and a calculation of the interplanar spacings of the crystal from these measurements, and a knowledge of the geometry of the apparatus and of the equivalent wavelength of the electron beam. Reference to published indexes of crystal data—together with a sufficient background knowledge of the particular problem to narrow the field of enquiry—should then enable the sample to be identified, providing the substance is one for which data are indexed.

EXAMPLES OF APPLICATIONS TO PRACTICAL PROBLEMS.

The various types of problem in which electron diffraction finds its application have already been mentioned. Many practical applications have already arisen during investigations at the Research Laboratories, from which the following three examples have been selected to illustrate the type of problem encountered. In each of these examples, the successful solution was dependent on the use of electron diffraction as the analytical tool. In many problems, however, a complete solution usually involves the application of several of the chemical and physical analytical techniques available.

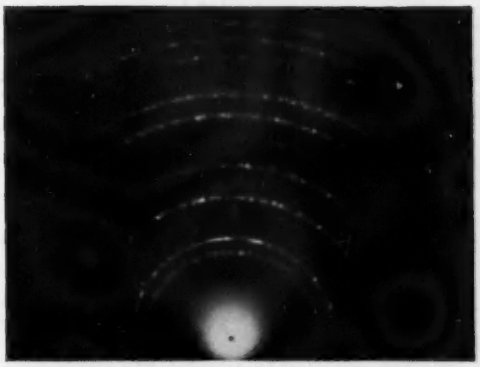

Fig. 5b.—Diffraction pattern from a limited number of larger crystals (magnesium oxide).

(*i*) In connection with development work on cathode ray tubes, several experimental tubes were found to give poor emission. Visual examination of the cathode showed a small darkened area, somewhat less than a millimetre in diameter, in the centre of the cathode coating. After examination by X-ray methods had failed to reveal the presence of any crystalline phase other than the normal cathode coating, an examination was made using the reflection electron diffraction technique. This clearly demonstrated the presence of graphite as a contaminant on the surface of the coating.

Fig. 6.—Diffraction pattern showing preferred orientation of crystals in the specimen (iron oxide).

(*ii*) At one period difficulty was experienced in applying the emissive coating to certain batches of nickel used for cathodes in radio receiving valves.

After normal processing the coating " flaked " away from the nickel base. These batches of nickel were found to comply satisfactorily with all the normal acceptance tests and they could not be distinguished

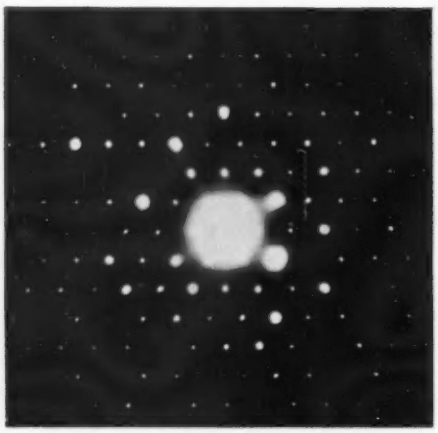

Fig. 7.—Single crystal pattern (mica).

from other batches of nickel to which the cathode coating adhered satisfactorily. As it appeared likely that any difference would be in the surface condition, samples of all the nickel were examined by electron diffraction. It was found that samples from each of the batches with which the flaking trouble was associated gave a diffraction pattern of hydrated calcium sulphate, whereas this pattern did not occur with any of the satisfactory nickel. Although this film probably occurred on the nickel surface to the extent of less than a hundred atoms thick—and was not detectable by any of the normal methods of test—it was apparantly responsible for the trouble experienced.

(*iii*) One of the problems which arose in connection with investigations being carried out in the Mineral Dressing department at the Research Laboratories concerned the nature of the surface film on " rusty gold." When the " amalgamation " method is employed for recovery of the gold, some of the metal may fail to amalgamate properly, leading to incomplete recovery. The gold particles which do not amalgamate may appear under the microscope to have a tarnished appearance; this condition is termed " rusty gold " in the mining industry. A sample of this character (from British Guiana) was the subject of the investigation referred to and it was decided to make an examination of a hand-picked sample by electron diffraction. The gold particles concerned were found to be coated with a layer of iron sulphide (pyrite).

These three examples serve to illustrate the function that can be performed by electron diffraction in supplementing the analytical facilities in a large industrial research organisation.

Remote Supervisory Control for the Southern Region, British Railways

By N. E. BARRETT and B. W. POPE,
Telephone Works, Coventry.

The G.E.C. is supplying to the Southern Region of British Railways all the remote supervisory control apparatus for their new control system in the London area. This will be the most extensive remote supervisory control system for railway electrification in Great Britain ; when completed, three control stations at Lewisham, Raynes Park, and Selhurst will control 73 substations, 72 track-paralleling huts, and a number of supply points and H.V. switching stations.

SUBSTATIONS on the London suburban lines of British Railways, Southern Region,[1] were equipped originally with rotary convertors under the direct control of substation attendants. The plant was fed by a 25 c/s power supply, which for the Western Section was generated at the Southern Region power station at Durnsford Road, Wimbledon ; and for the Central and Eastern Sections at the Deptford power station, built by the London Electricity Supply Corporation specially for serving the railway. Power was supplied to the tracks at 600 volts (later raised to 660 volts) D.C.

At the end of the recent war the plant at the railway power station, and in the substations, was reaching the end of its economical life, and the load was continuing to grow. The Deptford power station (now belonging to the C.E.A.) had been extended and reconstructed for 50 c/s, and a comprehensive scheme was therefore planned to replace the rotary convertors by remotely controlled mercury-arc rectifier substations, and to feed them from a new 33 kV, 50 c/s distribution system.

The new distribution system comprises a number of interconnected ring-mains, fed from three C.E.A. substations and two C.E.A. generating stations. The supply from one of the latter is taken at 66 kV and fed to the railway distribution system through 66 kV/33 kV on-load tap-changing transformers at South Bermondsey, Nunhead, Brockley, and Lewisham traction substations. Interconnection with existing 33 kV railway supplies is made at a number of other points. Power is fed to the substations over three-core oil-filled cables, supplied by the Pirelli-General Cable Works, Ltd., and low oil pressure alarms[2] are brought into a number of traction substations for extension to the control rooms.

The conversion scheme is now being carried out. The substation plant being installed will enable the track voltage to be raised from 660 volts D.C. to 750 volts D.C. when required.

TRACTION SUBSTATIONS.

At the traction substations the Up and Down tracks are fed from the D.C. busbars via high-speed track-feeder breakers. The substations are of a standard design, the capacity and size varying according to the number of tracks served. A substation building houses one, two or three rectifier units, two or more oil circuit breakers, and five or more high-speed D.C. circuit breakers. One transformer is required for each rectifier, and is located on the track side. Connections from the transformers to the substation negative busbar are made via outdoor shunts, which are installed so that the load can be measured at any time.

All switchgear-control wiring is carried in overhead trunking and terminates in a roof-suspended marshalling box, below which stands the supervisory control equipment cabinet.

All pilot cables along a route enter the substation. They are made-off in pilot terminating boxes and looped-through, teed off, or terminated there as required.

Each substation is equipped with a 50-volt battery for supervisory control.

TRACK-PARALLELING HUTS.

A track-paralleling (T.P.) hut is situated approximately midway between a pair of adjacent substations. Track-closing high-speed breakers connect all tracks electrically in parallel at these points for normal working, by connecting them to a common busbar. The breakers also enable sections of the track to be

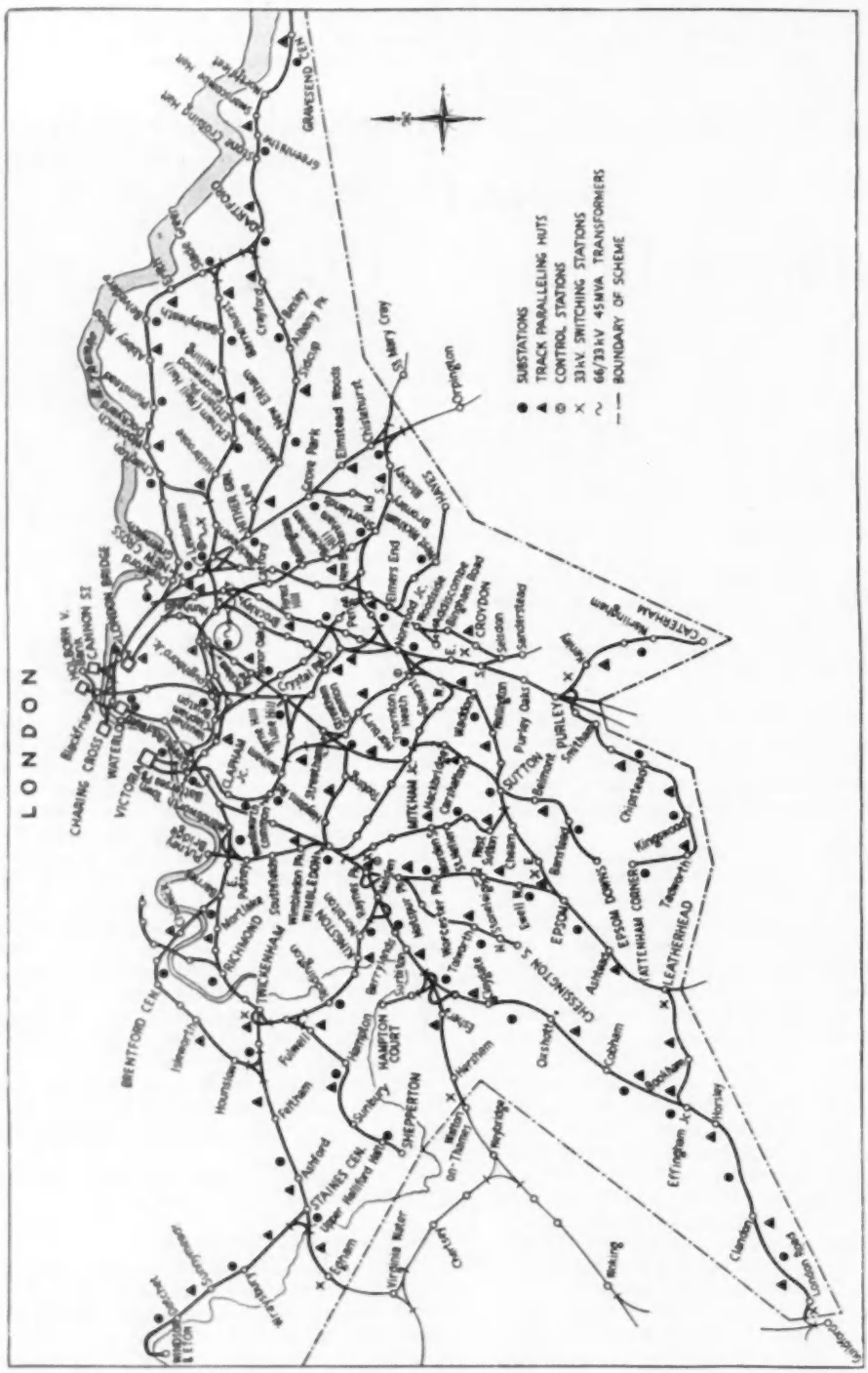

Fig. 1.—Southern Region electrified lines in the London suburban area, where remote supervisory control apparatus is being installed in connection with [the change-of-frequency scheme.

isolated, when required, e.g. for faults, or for maintenance on the track.

These breakers are normally arranged to close from the track supply. However, when a track cannot be energised from a substation, the T.P. hut busbar can be energised from another track, and the circuit breaker to the affected track closed by remote control. A 24-volt battery is installed in the T.P. hut to energise the contactors when the circuit breakers are closed in this way. The battery is charged from an adjacent substation.

SUBURBAN AREA.

The extent of the area covered by the change-of-frequency scheme is shown by the diagram of routes (fig. 1). The area is divided among the three sections of the Southern Region, each section having its own control station as follows :

Western Section—Raynes Park
Central Section—Selhurst
Eastern Section—Lewisham

The control vested in the control stations covers the railway's E.H.T. feeder circuit breakers in the substations of the Central Electricity Authority, and the whole of the plant within the railway substations and track-paralleling huts.

A number of substations on the fringe of two sections have plant controlled from two control stations, and arrangements are made so that, in an emergency, all the plant at essential substations in this category may be controlled from either of the control stations that normally control one part.

REMOTE CONTROL.

C.E.A. substations, traction substations, and T.P. huts adjacent to the control stations are controlled direct over multicore pilot cables. Other traction substations are controlled by a four-wire D.C. signalling supervisory system, arranged for tandem working. C.E.A. substations and T.P. huts are satellited on adjacent traction substations.

FACILITIES.

The facilities provided by the remote control equipment are:

Control and indication of feeder and interconnector oil circuit breakers.
Control and indication of rectifier A.C. oil circuit breakers.
Indication of discrepancy between rectifier A.C. and D.C. breakers.
Control and indication of D.C. track breakers.
Control of on-load tap-changing transformers.
Indication of transformer-tap position.
Indication of low oil pressure in oil-filled feeder cables.
Indication of a substation common alarm. Comprises : 50 volt charger fail, 110 volt charger fail. Rectifier fault. Buchholz fault. One of a pair of rectifier D.C. breakers open (C. and E. sections only).
Indication of bus alive.
Indication of track-paralleling hut breakers.
Control of track-paralleling hut breakers (when necessary).
Control and indication of the mass-control of any 2 or more track breakers in a predetermined group of 8 breakers.
Control and indication of the emergency " take-over " of all, or part, of a substation normally controlled from, and indicating to, another section control station.
Indication of breakers normally controlled from, and indicating to, another section control station.
Selection and display of A.C. feeder voltages from certain traction substations.
Indication of synchronism between two selected A.C. feeder voltages.
Selection and display of the summated rectifier loads from multi-unit traction substations.
Indication of average load on each C.E.A. feeder.
Indication of the tripping of track feeder breakers on the Waterloo & City line by means of the " pinch-wire " control.
Control of the resetting of the pinch-wire tripping relays.
Control of the facility for locking-out the closing circuit of an O.C.B., at a fringe substation, controlled from another section control station.
Indication that an O.C.B., at a fringe substation, is locked-out, or not, by another section control station.
Indication of supervisory faults.
Indication of pilot-cable faults.

COMMUNICATION.

Communication facilities are provided:

Between control rooms in the area.
Between the control rooms and the control points in neighbouring areas.
Between a control room and the C.E.A. substations in the section.
Between a control room and the traction substations and T.P. huts in the section.

SUPERVISORY CONTROL TANDEM SYSTEMS.

The substations in each section are controlled by a number of separate supervisory tandem systems, up to four substations being controlled in each system. All routes can be made alive should half the supervisory systems be put out of service.

The relay and uniselector equipment at each control station is divided between two apparatus rooms. A separate 50-volt battery is provided for each apparatus room, but under normal working the batteries are paralleled.

Adjacent substations on a route are controlled by different supervisory systems as shown in fig. 2. The control station equipment for the substations connected to system 1 is housed in apparatus room 1, and the equipment for the substations connected to system 2 is housed in apparatus room 2. T.P. hut breakers are self-closing when the track is made alive, but can also be closed by supervisory control via adjacent substations, each substation controlling the breakers of the track running towards the next substation on the route. Thus, as shown typically in fig. 2, if system 2 fails for any reason, the complete route can be made alive from substations 2, 4 and 6, controlled by system 1.

The number of controlled devices in a substation varies from one station to another. Some of the larger substations are split into two, the equipment being housed in adjoining buildings, which carry the substation name with an "A" or " B " suffix. When all the switchgear is controlled from one station, the supervisory equipment is located in one building. A

pilot cable between the buildings conveys the control and indicate signals from the switchgear in the other building. When the control of the switchgear is from two control stations, then the supervisory equipment connected to one control station is housed in the "A" building, and the equipment connected to the second control station is in the "B" building.

Speed of control is of considerable importance. To keep the time of a cycle down to a minimum, consistent with economy in equipment, a limit has been set to the number of devices which must be scanned during any control or indication cycle.

The equipment at each substation is shared between a number of control units, each unit accommodating a number of controlled or indicated devices, which has been selected as a compromise between speed in operation and economy in the number of units required. The speed requirements, and other considerations peculiar to the control of a traction system, make sub-division necessary within the units themselves in order to cover the following functions :

(*a*) Meter selection, check cycle start.
(*b*) A.C. switchgear.
(*c*) D.C. switchgear.
(*d*) Miscellaneous controls or indications.

In a traction system of this size it is now normal to have to carry out the multiplicity of operations for energising a track route, rather than the single action of reclosing a tripped breaker. The control and back-indication functions are performed by separate equipments to reduce the time required to set-up a track route via substations arranged for control in tandem groups. Thus, a change of indication in one substation will not hold up, or prevent, a control operation in another substation even though they are in the same tandem group.

The track breakers may be closed singly or in mass. The eight breakers controlled by one unit can be operated simultaneously. When all the breakers in a substation are to be operated, those controlled by unit 1 operate first, followed by those controlled by unit 2 and so on until all the breakers have operated. The same operation must be performed by all breakers, i.e. either close or trip ; the OPEN or CLOSE key is only pressed once. This feature considerably shortens the time required to put a route on load.

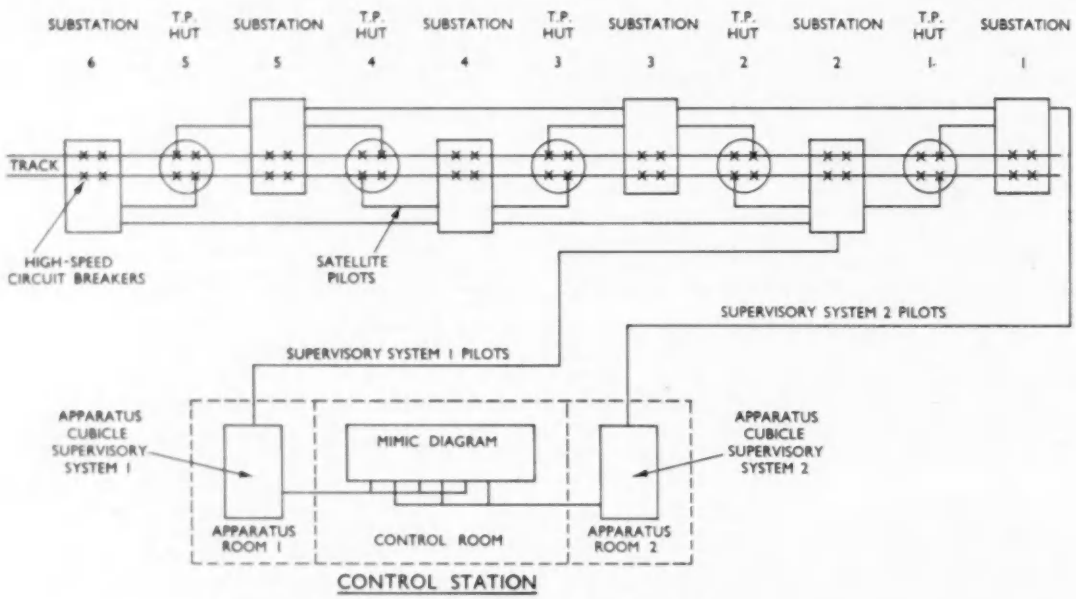

Fig. 2.—Diagram of control connections to substations.

Capacities of units of each type are as follows :—

QUANTITIES.

Per Unit.

A control unit comprises:

(*a*) Meter selection.
Check cycle start.
(*b*) 1 rectifier A.C. breaker or A.C. feeder O.C.B.
3 A.C. feeder O.C.B.s, bus section isolators, or A.C. O.C.B. lock-out.
(*c*) 8 track-feeder D.C. breakers.
(*d*) 2 A.C. breakers.
Alternative control take-over (when required).

An indication unit accommodates:

(*a*) 1 rectifier D.C. breaker.
1 rectifier A.C. breaker or A.C. feeder O.C.B.
3 A.C. feeder O.C.B.s, bus section isolators or A.C. O.C.B. lock-out.

(*b*) 8 track-feeder D.C. breakers.
(*c*) Cable low oil pressure alarm.
Substation common alarm.
Alternative control taken-over.
Meter connected.
D.C. bus alive.

The track feeders may be either substation breakers or T.P. hut breakers, or a mixture of both.

An indication unit can be arranged to accommodate in (*b*) 11 transformer tap indications and in (*c*) Buchholz and temperature alarms.

Per Substation.
Up to four units.

Per Tandem Group.
Up to six substations.

PER SECTION.

Central.	
9 tandem groups.	1 C.E.A. substation.
27 substations.	451 controls.
23 T.P. huts.	593 indications.
Eastern.	
10 tandem groups.	1 C.E.A. generating station and 1 substation.
34 substations.	482 controls.
23 T.P. huts.	663 indications.
Western.	
12 tandem groups.	2 C.E.A. substations.
35 substations.	502 controls.
26 T.P. huts.	643 indications.

CONTROL STATIONS.

The control stations are single-storied buildings. The control room proper (fig. 3), which houses the mimic diagram panel and the engineer's desk, is flanked by the apparatus rooms accommodating the remote-control equipment. At the ends of the apparatus rooms lie the two service rooms, in which the pilot cables are terminated and the battery chargers are housed. The battery room, in which two 50-volt batteries and a 150-volt selective-ringing signalling battery are situated, is an annex to the control room.

Offices are provided for the Control Supervisor, Track and Cable Inspectors, and the staff. A telephone room, workshop, storeroom and garage are also accommodated in the building.

MIMIC DIAGRAM.

The high-voltage feeder system, rectifiers and track feeders controlled from a control room are shown on a mimic diagram. The diagrams in all three control rooms are 29 ft. 5 in. long and 7 ft. 7 in. high. Their fronts consist of 22-in. square panels,[a] finished matt eau-de-nil, mounted above a 3-in. high black plastic kicking panel. The end panels, back, and a thin strip framing the top are finished light and admiralty grey. The diagram is built on the front of cubicles, which contain the necessary apparatus. The cubicles are each 3 ft. 8 in. wide.

The high-voltage oil circuit breakers, rectifier oil circuit breakers, and the track feeder high-speed circuit breakers are represented on the mimic diagram by discrepancy keys, which can be mounted on 1-in. centres. The handle of the discrepancy key is used to break or complete the diagram lines, and is coloured to match the lines in accordance with a colour-code.

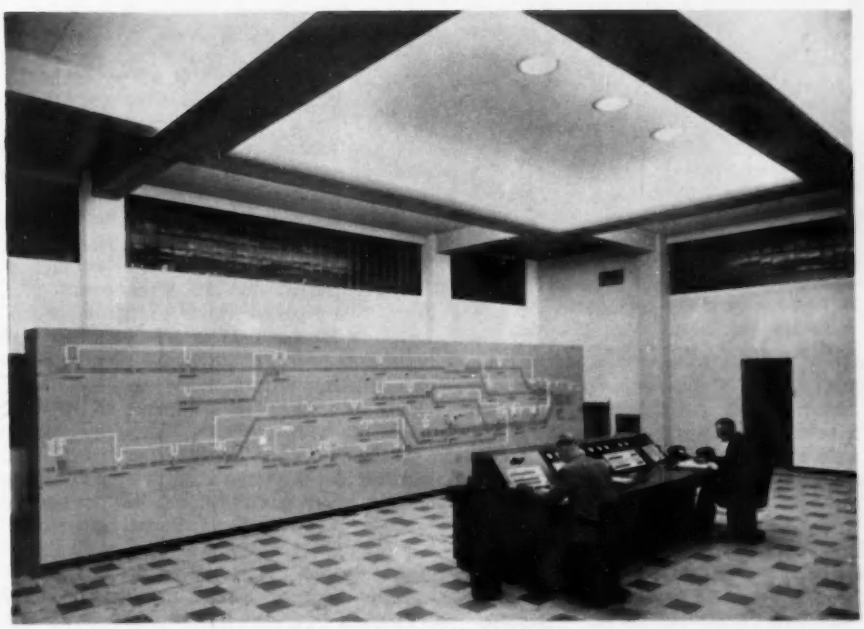

Fig. 3.—Raynes Park control room.

Diagram lines connecting breakers controlled only under emergency conditions are shown as two thin parallel lines of the representative colour.

Fig. 4 shows the layout on the mimic diagram of the switchgear at a substation and illustrates how the spacing of the discrepancy keys on 1-in. centres facilitates the representation of multi-track main lines.

There is a complete set of controls and indications

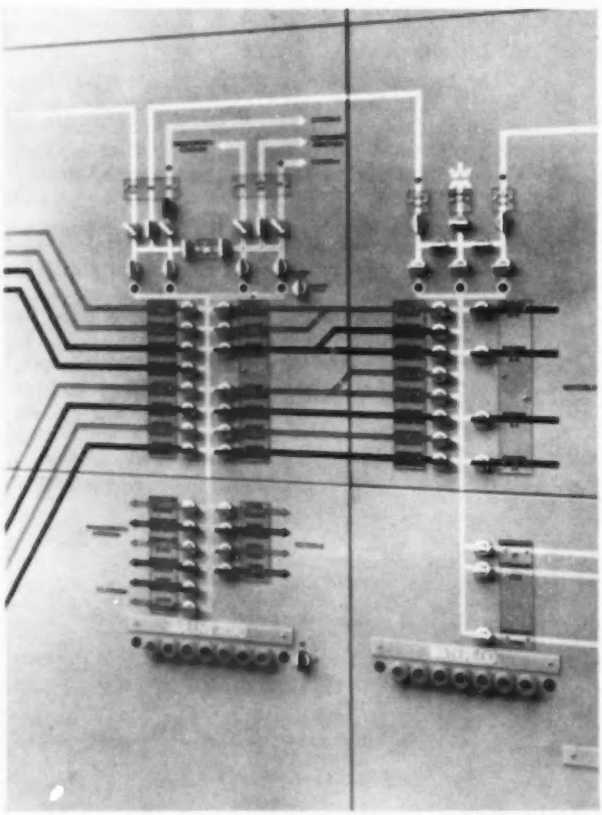

Fig. 4.—A section of the mimic diagram at Raynes Park, showing the close spacing of discrepancy switches.

for each substation, the arrangement of each set being the same. From the top downwards they are : low oil pressure alarm lamps, A.C. breakers, rectifier A.C. breakers, rectifier D.C. breaker indications and busbar alive indication when fitted, and track-feeder breakers. The substation name label is fitted beneath the breaker discrepancy keys, and below the name label are two indicating lamps in line with six push buttons and the substation alarm lamp. The common circuits are controlled by these push buttons, the knobs of which are illuminated when they are required to be operated. The panel is said to be "dressed" when all discrepancy keys represent correctly the conditions of the switchgear concerned, and there are no alarms. In this condition, the panel is completely "dark".

Additional discrepancy keys can be added if and when necessary, or if a major change is required a completely new 22-in. panel may be fitted in place of an existing panel. The diagram can, if necessary, be extended at either side by as many two-panel widths as may be accommodated in the control room.

Access to the key wiring is by hinged double doors at the rear of each cubicle. Each key is wired separately to the terminals at the rear of the cubicle to allow any key to be withdrawn completely to the back of the cubicle for maintenance without disturbing the wiring of any other key.

When permission is given to work on a breaker at a substation the discrepancy key handle representing the breaker on the mimic diagram is covered by a shield magnetically attached to the panel. This allows the state of the breaker to be seen, but prevents the key knob from being operated.

THE ENGINEER'S DESK.

The control desk, made of Honduras mahogany, accommodates the telephone switchboard, an alarm panel, metering equipment, and transformer-tap control and alarm equipment. The wings of the desk form writing tables for two control engineers, and allow easy exit for movement from the desk to the wall diagram.

The cordless switchboard is housed in a turret on the left hand wing. Facilities are provided for calling, by dialling, any track-paralleling hut or substation having switchgear controlled from that control room. Direct lines are provided to C.E.A. stations feeding into the section, and to other control stations which control contiguous tracks. Two conversations may take place simultaneously; the telephone on either wing can be connected to any line.

A second telephone on each wing is connected to the switchboard of the railway telephone room at the control station. At Raynes Park and Lewisham a third telephone on each wing is connected to the Waterloo & City pinch-wire telephone circuits.

Alarm lamps in the turret of the right-hand wing are arranged in vertical rows, one for each tandem system. The right-hand and left-hand rows are associated with the tandem system equipment in the right-hand and left-hand apparatus rooms respectively. The top lamp in each row lights to indicate a pilot fault, the second lamp indicates a fault in the tandem system common equipment, and the remaining lamps indicate a fault in substation equipment. A lamp is provided for each substation in the tandem system. Additional lamps give indications of blown

fuses in the apparatus rooms, or battery charger failure.

The centre turret of the desk houses the metering equipment, the transformer tap-change equipment, and an eight-day clock. The metering equipment, except for a frequency meter above the clock, is duplicated, the left-hand equipment being laid out as a mirror image of the right-hand side.

A lamp is inserted into the rear of each wing of the desk in such a position that one or the other can be clearly seen from any point of the panel diagram. These are indicating lamps for the check synchronising facility.

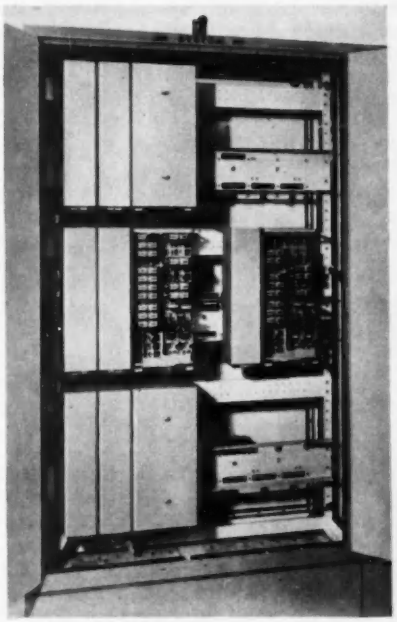

Fig. 5.—Control equipment for one two-unit and two single-unit substations.

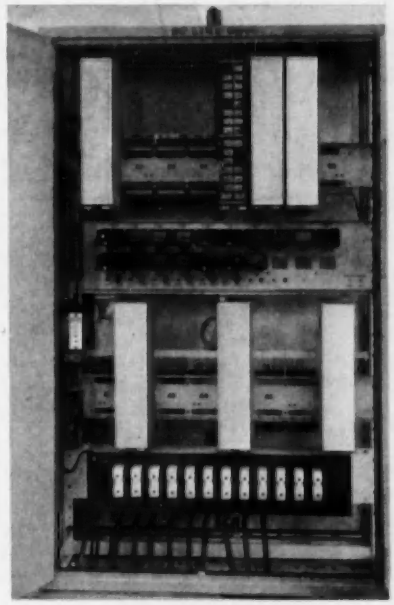

Fig. 6.—Line termination and selective ringing units.

CONTROL STATION APPARATUS ROOM.

The layout of all cubicles is similar with the exception of the line unit, one of which is installed in each apparatus room.

Each cubicle (fig. 5) is fitted with three shelves for jack-in relay sets. Each shelf is wired to accommodate two single-unit substation equipments, each of which consists of a substation common circuit, a unit common circuit, and a unit points circuit. For substations of more than one unit capacity, a meter circuit, or alternative control circuit jack-in plate, can be fitted in the same position as would be taken by the substation common circuit of the second, third and following units.

The basic wiring of each shelf in all cubicles is identical. Particular facilities required at each substation are provided by straps inserted on the terminal strips at the rear of each shelf. Points plates are all capable of being equipped with all facilities provided by a unit, but are fitted only with the equipment required for the particular substation being controlled. The equipment for substations controlled by a tandem system is grouped together in a cubicle as far as possible.

The line unit (fig. 6) houses the line relays and the tandem-system common-circuit relay plate for each tandem system controlled via that apparatus room, together with an apparatus room common relay plate, telephone-circuit relay plates, pilot-testing equipment and the 50-volt battery-distribution equipment.

Three-electrode gas-filled protectors are used to protect the supervisory equipment from high-voltage surges on the pilots and are fitted in metal boxes situated above the cable terminations in the service room.

SUBSTATION EQUIPMENT.

At the substations (fig. 7) the equipment is housed in double-walled[4] steel cabinets 7 ft. 6 in. high by 2 ft. 6 in. wide by 1 ft. 6 in. deep fitted with hinged double doors, front and rear, and finished dark admiralty grey to match the switchboard and other metal work in the substation.

A fully-equipped cubicle is fitted with three shelves ;

each shelf accommodating a unit common and unit points jacked-in plate and, when required, a satellite points plate. On the middle shelf only, a substation common plate is fitted. In substations requiring more than three units a second cubicle is fitted. The basic wiring of all shelves and substation cubicles is identical. Individual differences in plant controlled and indicated are catered for by strappings on the terminal strips at the rear of each shelf.

The cubicles (fig. 8) are flexibly mounted on a 9-in. high stool to prevent vibrations caused by the passing of trains on nearby tracks affecting the supervisory gear. A marshalling cabinet, of the same plan area as the supervisory cubicle, is suspended from the roof immediately above the supervisory cubicle. The small wiring in the substation is connected via terminals in the marshalling box. A waystation telephone equipment is bolted to the side of the supervisory cubicle.

An interposing voltage transformer, for each indication of feeder voltage required, is mounted on the feeder-switchgear panel.

At each multi-unit substation a summation magnetic amplifier connected to the D.C. kilowatt-hour metering shunts of the rectifiers provides an indication of the total D.C. load.

Where the substation plant is housed in two buildings an input summation magnetic amplifier is installed in each building, and a third amplifier is provided to sum the outputs of the other two amplifiers, to avoid running shunt leads between the two buildings.

Gas-filled line protectors are connected to the control and indicate pilots, meter pilots, and to the satellite pilots going to adjacent track-paralleling huts.

Fig. 7.—New standard design of rectifier substation at Brockley, Central Section.

TRACK-PARALLELING HUT EQUIPMENT.

The small amount of equipment required at the T.P. huts is housed in a wall-mounting steel cabinet fitted with a hinged lid. The cabinet is fitted with terminal strips and the relay equipment is mounted on jacked-in plates. The cabinet is usually fitted to an iron framework alongside the pilot terminations and a waystation telephone equipment is fitted below the supervisory cubicle.

CABLING.

The various items of supervisory apparatus at a control station are inter-connected by multicore P.V.C. insulated lead sheathed cables run in ducts beneath the apparatus room and control room floors. All cable wiring is terminated on terminal strips.

The substation wiring between the supervisory cubicle, marshalling box, line protection equipment, and pilot terminations is carried out in multicore P.V.C. insulated cable run in overhead metal trunking.

All cable for control stations and substations was supplied by the Pirelli General Cable Works Ltd.

The supervisory control cables (40 lb. multicore) were laid on the basis of 2 wires (1 pair) for control and 2 wires (1 pair) for back indication, for each tandem group. The cable also contains cores for feeder protection, selective ringing telephones, Pulsyn-etic slave clocks (giving time-controlled pulses), integrating watt-hour meter pulses, indication of A.C. voltages, and rectifier load.

D.C. ampere metering pilots are allocated at one pair per tandem system. As indication of the substation D.C. load is obtainable only from substations equipped with two or more rectifier units, some meter pilots serve only one substation and the output of the magnetic amplifier is connected directly to the pilot

pair at the substation. Where two or more substations share a pilot the magnetic amplifier output is connected to the pilot by the supervisory selecting equipment at the substation.

A.C. feeder-voltage metering pilots are not allocated on a tandem basis, but, as with D.C. ampere metering, some substations have exclusive use of a pilot whereas others are shared by a number of substations. Further, several indications are required from some substations and from others only one. Where an indication has exclusive use of a pilot pair, selection equipment is not required at the substation, and the interposing voltage transformer is connected directly to the pilots.

DIRECT-WIRE CONTROL.

Direct-wire working is used at Lewisham and Raynes Park substations and one or two T.P. huts as the distance to their respective control stations is small. The mode of operation at the wall diagram is the same as for breakers controlled via tandem systems.

OPERATING PROCEDURE.

An A.C. breaker is closed from a control station by turning the corresponding discrepancy key through 90 deg. so that the handle completes the diagram line. The lamp in the handle of the key and the nameplate lamps showing the location of the substation glow, and the knob of the CLOSE push button glows red. By depressing the CLOSE push button, the control pulses are transmitted and the lamps in the CLOSE knob and the nameplate are extinguished. The CANCEL lamp flashes if any other substation is already using the tandem-system equipment, or glows steadily while the control pulses are being transmitted. The control operation can be stopped by depressing the CANCEL push key at any time while it is illuminated.

When the control operation is completed, the CANCEL push-key knob is darkened, and the discrepancy key lamp and the substation nameplate lamps flash until the back indication that the breaker is closed is transmitted. The discrepancy key lamp is then extinguished. The substation nameplate lamps are extinguished at the termination of the back-indication pulses.

The procedure for tripping an A.C. breaker is the same except that the key is turned so that the handle breaks the diagram line, and that the knob of the OPEN push button is illuminated and is depressed to trip the breaker.

When an A.C. breaker is closed to put a rectifier on load, the back indication that the A.C. breaker has closed causes the D.C. breaker discrepancy lamp to flash to indicate that excitation of the rectifier is in progress. When the D.C. voltage is correct, the D.C. breaker closes, and the D.C. breaker discrepancy lamp, together with the substation nameplate lamps, are extinguished.

When a breaker trips under fault conditions, the alarm bell rings in the control room and the breaker discrepancy key lamp, and the nameplate lamps of the substation concerned, begin to flash, while the STOP ALARM push button knob is illuminated. The operator can extinguish the lamps and silence the bell by turning the breaker discrepancy key to the open position, to agree with the new condition of the breaker; or the alarm bell may be silenced and the STOP ALARM lamp extinguished, by momentarily depressing the STOP ALARM push button, but in this instance the lamp in the discrepancy key continues to glow and a buzzer sounds until the discrepancy key is turned to the open position.

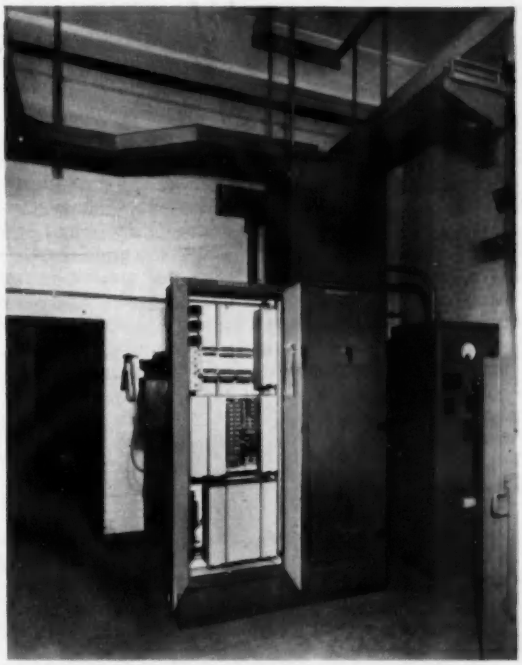

Fig. 8.—Duplicate control cubicles at Brockley substation, where switchgear is operated normally from two control rooms, but can be wholly controlled from either if necessary.

The track breakers may be opened or closed singly or in mass. The eight breakers controlled by one unit can be operated simultaneously, but, furthermore, all track breakers in a substation may be operated by depressing the OPEN or CLOSE key once. The breakers in the first unit operate, followed a few seconds later by those in the second unit, and then in each of any other units in turn. The same operation must be performed for all breakers, i.e. either close or trip. This facility considerably shortens the time required to energise a track route.

The discrepancy key lamps associated with track paralleling hut breakers and the station nameplate

lamps of the controlling substation, flash as the T.P. hut breakers close automatically when the track is made alive. The STOP ALARM push key lamp of the substation glows. These lamps are extinguished when the panel is " dressed ".

An alarm, either low oil pressure or substation fault, causes the appropriate lamp and substation nameplate lamps to flash and the STOP ALARM push button knob to be illuminated. The alarm bell rings. Momentarily depressing the STOP ALARM push key silences the bell and extinguishes the station nameplate lamps. The alarm lamp continues to glow for the duration of the fault condition.

A check to prove that the condition of the switchgear at a substation is as shown on the mimic diagram can be made by depressing the CHECK push key of the substation concerned. The lamp in the CHECK push key knob and the substation nameplate lamps flash. The nameplate lamps are extinguished and the CANCEL push key lamp glows while the control pulses for starting the check cycle at the substation are transmitted. The nameplate lamps again flash while the back indications are being received. At the completion of the check cycle the lamp in the CHECK push key and the nameplate lamps are extinguished.

All key and alarm lamps for a substation can be checked by depressing the LAMP TEST push key, when all the lamps should light. This facility is essential with a " dark " panel as an alarm state cannot be indicated directly when a lamp is burnt-out. However, the sounding of the alarm bell draws attention to the panel and the flashing nameplate lamps to the substation concerned. An otherwise dark panel suggests a burnt-out lamp and this, and the device in the alarm state, can be identified with the aid of the LAMP TEST push key.

To test the substation nameplate lamps the LAMP TEST key fitted on the alarm panel of the desk is operated, and the nameplate lamps of all substations on the control diagram should light.

D.C. AMPERE INDICATION.

On the engineer's desk, a substation selection key, together with a meter CONNECT lamp and PILOT BUSY lamp, are duplicated for each substation from which D.C. ampere metering is required. The meter pilot is connected to an instrument having a full-scale deflection of 30,000 amp. or 10,000 amp. by the upward or downward throw of a key. When a substation has its own pilot, the appropriate instrument is connected to the pilot by the key, the CONNECT lamp above the key glows, and the PILOT BUSY lamps glow both above the key and on the other side of the desk. The instrument then shows the D.C. ampere load on the substation as long as the key is left thrown.

Operation of the key of a substation sharing a D.C. metering pilot causes the CONNECT lamps to flash, and the PILOT BUSY lamps to glow, on both sides of the desk, for all substations connected to the pilot. The magnetic amplifier output at the substation selected is connected via the supervisory equipment to the metering pilot. The back indication from the substation when the magnetic amplifier is connected causes the CONNECT lamp above the substation selection key to glow steadily. Restoring the key causes the magnetic amplifier to be disconnected from the pilot by the supervisory gear. The PILOT BUSY lamp remains glowing until the disconnection is completed and the back-indication received at the control station.

HIGH-VOLTAGE FEEDER VOLTAGE METERING.

A selection key, CONNECT lamp and PILOT BUSY lamp are provided in duplicate on the engineer's desk, for each feeder from which voltage readings are required. An instrument having a full-scale deflection of 40 kV is fitted in each side of the desk. The mode of operation for individual and shared pilots is as described for D.C. ampere metering.

Although permission has to be obtained from the C.E.A. before closing any breaker which will connect together two different C.E.A. supplies, means are provided for the control operator to check that the two supplies are in synchronism before the breaker is closed. Voltage readings are obtained on the two voltmeters on the desk from convenient feeders connected to each C.E.A. supply. The CHECK SYNCHRONISING key, on either side of the desk, is then operated to disconnect the pilots from the two voltmeters and connect them to the check synchronising equipment. The lamp above the CHECK SYNCHRONISING key, and a lamp on the rear of each wing of the desk, flash. When the two voltages are in synchronism the lamps glow steadily, and the operator may then close the breaker, which will parallel the two supplies.

HIGH-VOLTAGE FEEDER LOAD METERING.

The average load for the previous half hour on each C.E.A. feeder feeding into the section controlled from a control room may be shown on either of the two megawatt instruments on the desk.

To obtain a reading for any feeder, the key on either side of the control desk associated with the feeder is operated and connects the instrument to the display group for that feeder. The average megawatt demand of the previous half hour is then displayed. The CONNECT lamp glows above the operated key while the instrument is connected. At Selhurst and Lewisham the instrument has two scales, 45 MW and 25 MW, one drawn in red and the other in black. The colour of the handle of the feeder-connect key indicates the scale to be read for that feeder.

45 MVA TRANSFORMER-TAP CONTROL AND INDICATE.

The 66 kV feeders from Deptford C.E.A. power station terminate on 45 MVA transformers at Lewisham, Nunhead, Brockley and South Bermondsey. Tap-changing equipment on the 45 MVA transformers at Nunhead, Lewisham and South Bermond-

sey is controlled from Lewisham. Selhurst controls the transformer at Brockley, and also, in an emergency, the transformer at South Bermondsey.

The tap position indicator, substation select, RAISE and LOWER keys, the temperature and Buchholz alarm lamps, and the STOP ALARM key are duplicated on the desk. The position of the tap on a transformer is displayed on the indicator by operating the required substation select key in the upward direction.

The transformer tap is changed by operating the substation select key downwards. The CONNECT lamp and the lamp above the RAISE-LOWER key glow and the tap-position indicator shows the present tap. If the tap is to be raised, the RAISE key is operated. This causes the code for the tap unit at the required substation to be transmitted, and raise the tap position. The back indication of the new tap position is transmitted from the substation, and the new tap position is indicated.

The temperature and Buchholz alarms are transmitted as any other alarm from a substation but a common STOP ALARM key on the desk is used to silence the alarm bell.

OUTLINE OF CIRCUIT.

The remote supervisory control system employed is a variation of a type known as total-count-check. In such a system the number of pulses comprising the code always has a constant total. Pulses of opposite polarity are used and for descriptive purposes are designated *positive* and *negative*.

Uniselectors are used as counting switches. A sending selector counts the number of pulses transmitted and encodes the intelligence; and a receiving selector counts the received pulses and assists in decoding the received signals.

The receiving selector is stepped by a train[5] of positive pulses. The intelligence is conveyed by a lesser number of negative pulses, which are inserted in varying positions in the gaps between pairs of positive pulses.

Fig. 9.—Switchroom at Brockley, showing the 33 kV switchgear.

The code must be such as to identify :—

The substation within a tandem group.
The unit within the selected substation.
The appropriate subdivision of the unit.
The device to be controlled (or indicated).
The operation to be performed. (Open, close, raise, lower.)

The need for separate identification of a substation has been avoided by allocating an individual code identity to each unit within a tandem group. In allocating the codes it was essential to avoid duplication within a tandem group on the occasion when the make-up of the group is temporarily modified by the inclusion of units, in fringe substations, taken over under emergency control conditions.

Fifteen unit-code combinations are obtained by inserting two negative pulses, in all the combinations of two-out-of-six, in the first six gaps in the train of positive selection pulses.

As all devices in a unit are scanned during an excursion through the unit, a code element is established for *select* and a further one for *not select*. Two adjacent outlets of the uniselector banks are allocated to each controlled device, and the portion of the transmitted code which can be considered to be peculiar to such a device is two positive pulses and one negative pulse. In the *non-select* element the negative pulse follows the second positive pulse. In the *select* element the negative pulse follows the first positive pulse. Thus the total number of negative pulses remains the same, for a given cycle, irrespective of the number of breakers to be selected for operation.

An actual count is made of the number of positive pulses received but the number of negative pulses is determined indirectly. The code-sensing element is such as to accept two negative pulses, neither more

nor less, in the unit code group, and one for each device scanned. Since the unit code has only two negative pulses, it cannot be mistaken for a group of three controlled devices.

The order of allocation of outlets of the uniselectors is :

Unit code.
Operation, close or open.
A.C. group.
D.C. group.
Miscellaneous group.

The sending selector is arranged to stop when the end of the A.C. group has been reached, but if a D.C. breaker is to be selected the stop circuit is transferred to the end of the D.C. group. A signal is extended to the substation, when the selector reaches the end of the A.C. group, to the effect that the receiving selector is to enter the D.C. group, and similarly with a device in the miscellaneous group. Each group thus has its own total-count-check outlet, and the operation to be performed is determined before entry is made into any of the groups ; this is therefore available to all groups without the necessity for duplication.

The initial signal of a selection pulse train seizes all units and the unwanted units are locked out as they fail the code test. Only the wanted unit can pass the test and proceed to the determination of the operation to be performed and to the selection of a controlled device. The receipt of a negative pulse when the receiving selector is on the *close* outlet causes the operation of a close *memory* relay. Similarly an open *memory* relay operates if the pulse is received while the selector is on the *open* outlet. A *memory* relay is provided for each of the controlled devices and the appropriate one (or more in the case of selection within the D.C. group) operates to its *select* code. Should the code sensing element detect an error in the code, the unit is locked out, and any operated *memory* relays released. Otherwise, when pulsing ceases and the total-count-check point is reached, the required operation is performed.

Back-indication of the state of the controlled devices and alarms is performed in a manner similar to that by which the devices are controlled. For ease of maintenance the controlled devices are allocated the same numbered outlets on both the control and indication selectors. This is made possible by allocating to the indicate-only rectifier D.C. breaker, outlets on the indication selector having the same number as the outlets on the control selector occupied by the *open* and *close* controls.

The *select* code element is used to indicate *closed* and *non-select* indicates open. The code-sensing element recognises absence of either signal and arranges for an indication of *faulty auxiliary contact*. A fault condition that gives a signal on both contacts causes the unit to lock-out. The lock-out gives rise to an alarm—as will any other condition which prevents the correct completion of a back-indication cycle. On acceptance of the alarm the back-indication cycle is repeated automatically.

To close an A.C. breaker the associated discrepancy key is turned to the *closed* position, and the CLOSE push button is depressed as already described under " Operating Procedure ". The breaker key changes the marking of its code wires from *not-select* to *select*, and on operation of the CLOSE push button all units in the tandem group are seized and the coded pulses transmitted. The *unwanted* units are locked-out as the unit-code pulses are received ; the *close memory* relay in the wanted unit operates, followed later by the required breaker memory relay. Pulsing ceases when the sending selector reaches the outlet which marks the end of the A.C. group. Cessation of pulsing should find the receiving selector, at the substation, on the A.C. group total-count-check outlet, and after a short checking pause the breaker closes. The controlling equipment restores to normal and the lamp in the key handle flashes.

The transition of the breaker from open to closed starts up the back-indication cycle. The units situated at the control station and in the tandem group concerned, are seized and the coded pulses transmitted. The *unwanted* units are locked-out as the unit-code pulses are received. All the devices in the A.C. group are scanned and the indication of the changed breaker is stored as *closed*. The lamp in the key handle, which was flashing, is extinguished.

If it is desired to close, say, eight track feeder breakers simultaneously, e.g. energise all sections of a four-track route, the appropriate eight keys are turned to *close*. All eight breaker points are thereby changed from *not select* to *select*. On operation of the CLOSE push key, the coded pulses are transmitted as described for the operation of an A.C. breaker, except that no memory relay is operated during the passage of the receiving selector through the A.C. group. When the outlet is reached which previously marked the end of the A.C. group, an indication is given to the substation that selection is proceeding into the D.C. group. Each of the eight memory relays in the D.C. group operates, and when the selection cycle has passed the total-count-check test, the eight breakers close simultaneously. Transition of the breakers from *open* to *closed* again initiates a back-indication cycle, completion of which extinguishes the lamp in the discrepancy key handles.

When a breaker trips on overload, or its state is changed by local control, a back-indication cycle is initiated during the transition period. The cycle stores the new indication which, as it differs from that indicated by the position of the key handle, causes an alarm bell to sound and the lamp in the key handle to flash. The substation nameplate lamps flash to draw attention to the affected substation on the diagram panel.

If it is assumed that a track-paralleling hut is satellited on substations 1 and 2, then when a track feeder in substation 1 is closed, a breaker in the T.P. hut will close automatically and its back-indication will be via substation 2. If that breaker in the T.P. hut later trips out on overload it can be reclosed via substation 2. After the trip indication has been

acknowledged, by turning the key to *open*, the key is turned to *close* and substation 2 nameplate lamps glow, indicating that control of the breaker concerned is via substation 2. The CLOSE push lamp for substation 2 glows, and is pressed to start the *closing* sequence.

At the station the closing pulse is extended over a pilot core to a breaker-controlling relay in the T.P. hut. When the breaker closes, the *closed* indication is transmitted to the substation over the same core as carried the *closing* signal. Indications passed from the T.P. hut to the substation are *light current* signals, one polarity indicating *closed* and the reverse polarity indicating *open*. The control signals passed from the substation to a T.P. hut are *heavy current* signals and again a change of polarity is used to differentiate between the two signals.

Control and indication of all circuit breakers situated in C.E.A. stations satellited on railway traction substations, is carried out in a manner similar to that used for the control and indication of T.P. hut breakers. The main difference is that controls are carried out over one core and back-indications are given over another.

Back-indications from all units of a substation can be *called-up* by operation of the substation CHECK push key. This causes a coded train of pulses to be transmitted to the substation. Transmission ceases before the A.C. group is reached and during the checking pause all units are put into an alarm state and the units transmit back-indications in cyclic order. On completion of the check of the last unit the lamp in the CHECK push knob, which flashed throughout the check cycle, is extinguished.

METER SELECTION.

Selection of metering point is performed by a brief cycle similar to that used for a check cycle. One outlet serves for both on and off switching by means of a flip-flop relay circuit. The selection and back-indication circuits are so interlocked that should the position of the relays be disturbed by hand during maintenance, the interlocks will function to restore the original condition.

DIRECT CONTROL.

Direct control of traction substations adjacent to the control rooms is carried out over four pilot cores, one each for *open* and *close* controls, and *open* and *close* indications. One core is used for each alarm. The distances are very short, being a matter of yards.

Direct control[6] of T.P. huts utilises the method of control already described for the extension of control to T.P. huts from supervisory-controlled traction substations, except, of course, that the control circuits are extended direct from the panel circuits and not via an intermediate substation.

EMERGENCY CONTROL.

Where a substation is subject to control from one (normally) or the other (in emergency) of two control rooms, control equipment for that substation is installed in both control rooms. Only one set of equipment is fitted in the substation to control a particular group of switchgear.

Queen's Road "A" is normally controlled from Raynes Park and Queen's Road "B" from Selhurst. In the "A" equipment at Queen's Road substation is a switching point, operated from Raynes Park, which is arranged to transfer connection of the "B" units from the line circuits connected to cables running to Selhurst to the line circuits already controlling the "A" units from Raynes Park. Thus, when Raynes Park takes over the units normally controlled from Selhurst, Queen's Road substation (Raynes Park control) "grows" from a three-unit substation to a five-unit substation.

To take over control of Queen's Road "B", the Raynes Park operator turns the EMERGENCY CONTROL key, situated at the right-hand end of the row of push buttons, from the *normal* to the *emergency* position, and the lamp in the handle glows, as do the control panel and substation nameplate lamps. Operation of the CLOSE push causes the transmission of a coded pulse train. On satisfactory completion of the total-count-check, the take-over relay operates and switches the "B" units to the "A" control equipment. A check cycle from the taken-over units is initiated automatically, to line-up the "B" sub-

Fig. 10.—The rectifier room at Brockley substation.

station back-indication equipment at Raynes Park control. Control of the "B" substation can then be effected from the "B" substation section of the panel at Raynes Park.

On expiration of the emergency the control operator at Raynes Park can hand back control of the "B" units to Selhurst by turning the control key from EMERGENCY to NORMAL and pressing the OPEN push. On completion of the switching operation a check cycle of the handed-back units is made automatically, to line-up the back-indication equipment at Selhurst.

Alternatively, the maintenance engineer can restore the normal condition by momentary operation of a RESET key at the substation. A *normal* indication would then be transmitted to Raynes Park, the alarm bell would sound, and the lamp in the handle of the EMERGENCY CONTROL key would flash, as would the substation nameplate lamps. The panel is then dressed in the usual way.

LINE PROVING.

Equipment for line proving is installed in each apparatus room. All supervisory lines entering an apparatus room are connected to the line circuits via access relays. The access relays are operated from the line-proving equipment, and by this means a selected quad is connected to a test circuit. Tests to detect incipient short-circuits, open-circuits or earth leakages are made on each quad serving a tandem group of substations, once in each half-hour. The pairs of a quad are tested separately, the control pair being tested first and then used to guard the substation and prevent it from attempting to transmit during the test on the back-indication pair.

If all lines were free from supervisory signals at the test period the quads would be tested in cyclic order. However, when either pair in a quad is being used by the supervisory equipment, the quad is busied against seizure by the line-proving equipment. At the test period a "start" signal is received from the control room electric master clock, the line selector hunts to the first free line, and the access relay operates. The testing element is of the null-balance type, and prior to a proving test on the control pair of each quad the test element is proved capable of detecting line faults. Should the test element be found faulty the test is abandoned and an alarm condition indicated. Otherwise the control pair is tested for high resistance, low insulation resistance, and leakage to earth. The test voltage applied to the line is of the order of 110 volts.

During the application of testing conditions to the control pair, the back-indication pair is bridged by a potential-detecting relay to guard against intrusion of a back-indication signal from any substation having access to that pair. If a potential is so detected, the test is abandoned and the quad is restored to the supervisory equipment to enable the back-indication cycle to be completed without interference.

On completion of the test sequence on the control pair a potential is extended to the substations to prevent transmission of back-indication cycles during the test sequence on the back indication pair. On completion of this test sequence a "test-completed" relay is operated which busies the quad against the line-test equipment. The line selector then seeks the next free quad and the test sequence is repeated, and then repeated again and again until all quads have been tested.

When a test sequence on any quad is completed, and no other quad is free, the line selector parks on the last-tested line until one becomes free. If the selector is hunting to the only free line when that one becomes busy, the line selector rotates to a parking point where it remains until a line is available.

During the test sequence on a quad, if a supervisory control operation is attempted, the test is abandoned and the line handed-back for supervisory use. When a test is abandoned the test-completed relay is not operated; therefore when the supervisory operation is completed, the line again becomes free for test.

When a line fault is detected the test is abandoned, an alarm indication given, and the test-completed relay operated, for in this event the test is considered completed.

At the commencement of each test period a check is made to determine if all lines have been tested during the previous half-hour. Unless all are found to have been tested an alarm indication is given. After the test has been made all quads are freed for test by the releasing of the test-completed relays. Any operated fault relays are not released until a test on the quad proves the fault to be clear.

When a line fault is detected the control operator is given an indication that a particular route is faulty but no indication of the nature of the fault is given as the information would be of little interest to him and three times the number of alarm lamps would be required on the alarm panel.

Facilities are available in the line cubicle for initiating the line-proving cycle, and for selecting any particular line and controlling the test sequence upon it. Should a fault be detected the test is not abandoned, but an indication of open-circuit, short circuit or earth leakage is displayed.

The testing voltage is obtained from a power-pack and is fed to the test element via a barretter, which serves the dual purpose of stabilising the test supply and limiting the current flowing into a full short-circuit.

MAINTENANCE.

The whole supervisory system has been planned bearing in mind the need for reliability and the least possible amount of maintenance, together with the need for any fault to be located and rectified very speedily. The circuits have been split up to mount the equipment on a minimum number of jacked-in plates so that a large number of spares is not required in order to be able to replace any suspected faulty plate by a known good one.

Failure of the equipment particular to a substation at the control or substation end, and failure of equip-

ment common to a tandem system, is indicated on the alarm panel of the desk.

Indicating fuses are fitted to all circuits at the control station, and a blown fuse causes a red lamp to glow at the top of the cubicle, also lighting an indicating lamp on the desk to show in which apparatus room the fuse has blown.

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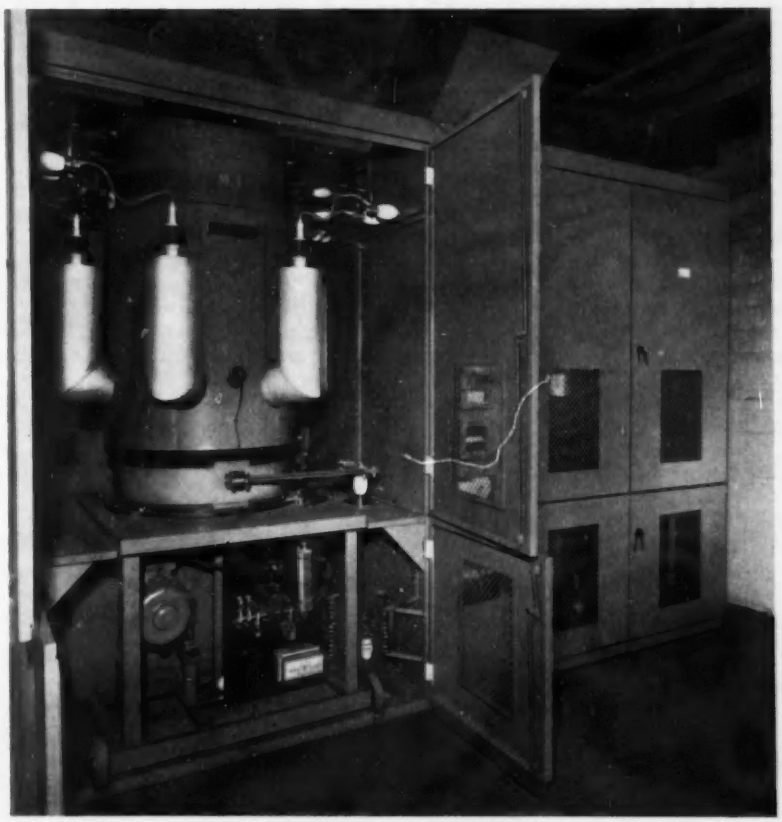

Fig. 11.—Rectifier cubicles at Brockley substation.

Corrimal Colliery — First Coal Preparation Plant in Australia

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INTRODUCTION.

THE Fraser & Chalmers Engineering Works of The General Electric Co. Ltd. obtained the licence to manufacture equipment for the Chance system of coal washing in 1931. Since then, thirty-seven plants have been installed, or are under construction, by the Company, with capacities ranging from 50 to 750 tons per hour. The process has been successfully introduced by Fraser & Chalmers into the United Kingdom, Europe, South Africa, India and, more recently, into Australia.

It is, perhaps, appropriate that the first plant to be installed in Australia should be in New South Wales, as the process has met with great success in Britain in the South Wales coalfield, where fifteen plants have been ordered up to the present time. The Australian plant was ordered early in 1953 by the Corrimal Coal & Coke Pty. Ltd. for its Corrimal Colliery.

The plant has a capacity of 200 tons per hour of 6 in. sq. × 0 raw coal, and the scope of the contract covered the whole of the civil engineering work, steel-framed building, bunkers, belt conveyors, driving motors, control and distribution gear, transformers, lighting and power wiring installation, in addition to the whole of the washery plant and ancillary equipment.

SITE DETAILS.

Corrimal Colliery, opened in 1868, is situated on the south coast coalfield of New South Wales, some 50 miles south of Sydney. The colliery is in a delightful setting in the bush, high on a mountain side overlooking the Pacific Ocean. The coastal plain near Corrimal is about three miles wide, from which the ground rises steeply to form an escarpment 1,500 ft. high. Coal is brought up a drift which runs in a westerly direction at an inclination of about 1 in 30, and has its mouth approximately 546 ft. above sea level.

Due to the ground contours, it was impracticable to bring railway sidings up to the drift, and the coal preparation plant has been constructed about a mile away on the plain below, about 426 feet lower than the level of the mouth of the drift (fig. 1). This feature necessitated special consideration being given to the raw coal handling arrangements between the drift and the plant, as described later.

Fig. 1.—A view from the mouth of the drift of the Chance coal-washing plant at Corrimal on the plain 426 ft. below.

RAW COAL.

In all, there are seven seams of coal on the property, which range from 4 ft. to 10 ft. in thickness. At present the No. 1 or Bulli seam is worked, and this is under cover of 300 ft. to 1,500 ft. with a dip of 1 in 50 in a north-westerly direction. The coal is a semi-bituminous, short-flaming, coking coal, and it burns with a marked freedom from clinker. The calorific value is about 13,000 B.Th.U's per lb., and it is relatively soft and free from dirt bands. A typical analysis of the coal is given in Table 1.

TABLE 1

TYPICAL ANALYSIS OF COAL

	Per cent
Water	1·9
Volatiles	24·1
Fixed carbon	62·7
Inherent ash	11·3
	100·0

The Bord and Pillar method is used for winning the coal, which until the end of the second World War was cut by hand. Shortly after the end of hostilities, an extensive programme of mechanisation was put in hand to overcome difficulties imposed by shortage of manpower, and increasing cost of wages and materials. It was found, however, as has been the experience in other parts of the world, that increased mechanisation resulted in a higher ash content of the run-of-mine coal. While the coal, in any case, has a relatively high inherent ash content, of the order of 12 per cent., the introduction of machine mining increased the total ash content to about 20-25 per cent. It was therefore decided to investigate the possibility of upgrading the coal by washing, in order to meet the requirements of a more exacting market. After exhaustive enquiries into the relative merits of various coal washing processes, it was decided to place the contract with the British General Electric Company (Pty.) Ltd., for a plant embodying the Chance process.

CHARACTERISTICS OF RAW COAL.

It is fortunate that the coal at Corrimal breaks down in such a way that the smaller the size, the lower the ash content. This is illustrated in Table 2, which gives the sizing and ash analysis of a typical sample of raw coal.

TABLE 2

SIZING AND ASH ANALYSIS

Size (in.)	Weight (per cent.)	Ash (per cent)
6 × 3	43·7	28·7
3 × 1	25·1	20·8
1 × ½	7·3	17·9
½ × ⅛	12·7	15·5
⅛ × 0	11·2	11·1
Total	100·0	22·3

In the main, the above characteristics are due to the fact that, unlike British coals for example, the shaley portions are more intimately mixed with combustible portions, and tend to occur in relatively thin bands. In British coals the shaley bands, being relatively thick, tend to break away from the larger sizes of coal and become concentrated in the finer sizes. The Bulli coal, on the other hand, does not in general contain bands of soft shale, but consists of bands of high-ash and low-ash coal; the high-ash fractions, being chiefly durain, are much less friable than the low-ash clarain and fusain fractions. As a result, the fines produced in the mining operation tend to have a lower ash content than the larger fractions. These characteristics are similar to those of Indian coals, of which Fraser & Chalmers has a wide experience.

These facts had a marked effect upon the design of the plant, and once again illustrate the necessity of an

Fig. 2.—Skips awaiting discharge by rotary tippler into the surge bunker.

individual study being made of any washing project before the method of treatment can be decided. It was, of course, apparent that in the circumstances no useful purpose would be served by resorting to the costly and relatively difficult problem of washing the fine coal.

Table 3 gives the washing characteristics of a typical sample of 6 in. sq. × 0 coal from the No. 1 Bulli seam. From these characteristics it will be noted that at 1·60 s.g., the theoretical yield of the 6 in. × ⅛ in. fraction is 72·34 per cent. at 10·2 per cent. ash, while the ⅛ in. × 0 fraction is 11·2 per cent. at 11·1 per cent. ash. Combining these a yield of 83·54 per cent. at 10·32 per cent. ash content is obtained.

It was anticipated that by washing the 6 in. × ⅛ in. fraction only, and mixing the ⅛ in. × 0 fraction back raw, a product of the desired ash content would be given; and that the moisture-content of the 6 in. × 0 raw coal would be such that it would not be possible to separate the ⅛ in. × 0 fraction from the feed by means of the conventional method of dry screening. Fraser & Chalmers has developed a method of wet screening successfully at sizes as small as 1/16 in. sq.* and this method was applied to the Corrimal plant for separation at ⅛ in. sq.

* *G.E.C. Journal*, Vol. 22, No. 2, pp. 105-116, April, 1955.

HANDLING ARRANGEMENTS FOR RAW COAL.

The raw coal is brought up the drift in skips of approximately 30 cwt. capacity, by means of a steam haulage engine. After uncoupling from the haulage rope, the skips gravitate to a rotary tippler, from which the raw coal is discharged into a surge bin (fig. 2). The latter is provided with a feeder, fitted with a bar

TABLE 3.

FLOAT & SINK AND ASH ANALYSIS OF 6in. × 0 RAW COAL AT CORRIMAL COLLIERY

(a) F. 1·35 to S. 1·55

Size In.	Floats 1·35 Sinks —			Floats 1·40 Sinks 1·35			Floats 1·50 Sinks 1·40			Floats 1·55 Sinks 1·50			Floats 1·60 Sinks 1·55		
	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points
6 × 3	11·84	7·8	92·35	19·63	10·6	208·08	1·40	19·7	27·58	0·01	28·2	0·28	0·01	32·4	0·32
3 × 1	5·71	7·7	43·99	13·69	10·2	139·64	1·76	16·5	29·04	0·07	26·6	1·86	0·02	29·8	0·60
1 × ½	1·79	7·7	13·78	3·69	10·6	39·11	0·94	16·5	15·51	0·06	26·4	1·58	0·04	32·2	1·29
½ × ⅛	5·09	7·4	37·66	4·80	11·0	52·79	1·55	16·8	26·03	0·15	24·7	3·71	0·09	31·8	2·86
⅛ × 0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	24·43	—	187·78	41·81	—	439·62	5·65	—	98·16	0·29	—	7·43	0·16	—	5·07

(b) F. 1·65 to S. 1·80

Size In.	Floats 1·65 Sinks 1·60			Floats 1·70 Sinks 1·65			Floats 1·80 Sinks 1·70			Floats — Sinks 1·80		
	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points	Wt. %	Ash %	Ash Points
6 × 3	0·03	38·5	1·15	0·08	43·2	3·45	0·04	53·0	2·12	10·66	86·20	918·84
3 × 1	0·02	36·2	0·72	0·02	38·8	0·78	0·20	49·9	1·00	3·61	84·32	304·42
1 × ½	0·02	38·0	0·76	0·03	43·2	1·30	0·06	51·4	3·08	0·67	81·10	54·34
½ × ⅛	0·05	36·8	1·84	0·05	42·2	2·11	0·10	51·9	5·19	0·82	78.8	64·62
⅛ × 0	—	—	—	—	—	—	—	—	—	—	—	—
Total	0·12	—	4·47	0·18	—	7·64	0.40	—	11·39	15·76	—	1342·22

Size In.	TOTALS (a and b)		
	Wt. %	Ash %	Ash Points
6 × 3	43·7	28·7	1254·18
3 × 1	25·1	20·8	522·05
1 × ½	7·3	17·9	130·75
½ × ⅛	12·7	15·5	196·81
⅛ × 0	11·2	11·1	124·32
Total	100·0	22·28	2228·11

Fig. 3.—Skip discharging into 200-ton capacity bunker.

grizzly at the discharge to pass a 6 in. product. The oversize material, i.e. the plus 6 in., is discharged into a single-roll crusher for reduction to minus 6 in., after which it joins the natural 6 in. × 0 fraction on a belt conveyor. The latter delivers the 6 in. × 0 into a 100-ton capacity bunker.

A haulage-way is supplied for lowering the raw coal down the incline from the colliery to the coal preparation plant. Two skips, each having a capacity of 15 tons, are fitted at each end of the haulage rope. The drive is automatic, and once the "start" push button has been pressed, the skips are accelerated to their normal speed, and then decelerated and brought to rest, without any further action on the part of the operator. The 100-ton capacity bunker mentioned above is fitted with power-operated doors for filling the skips as they reach the top of the incline.

On reaching the bottom of the incline, the skips run over the top of a 200-ton capacity bunker. Power-operated bottom discharge doors are fitted to each skip to enable the contents to be discharged into the bunker (fig. 3). The latter is fitted with a scraper-feeder to regulate the rate of feed to the washery.

COAL PREPARATION PLANT.

The coal is delivered to the plant by means of a 30 in. wide belt conveyor (fig. 6). The latter discharges

Fig. 4.—Sherwen raw coal screen for screening at ½ in. square.

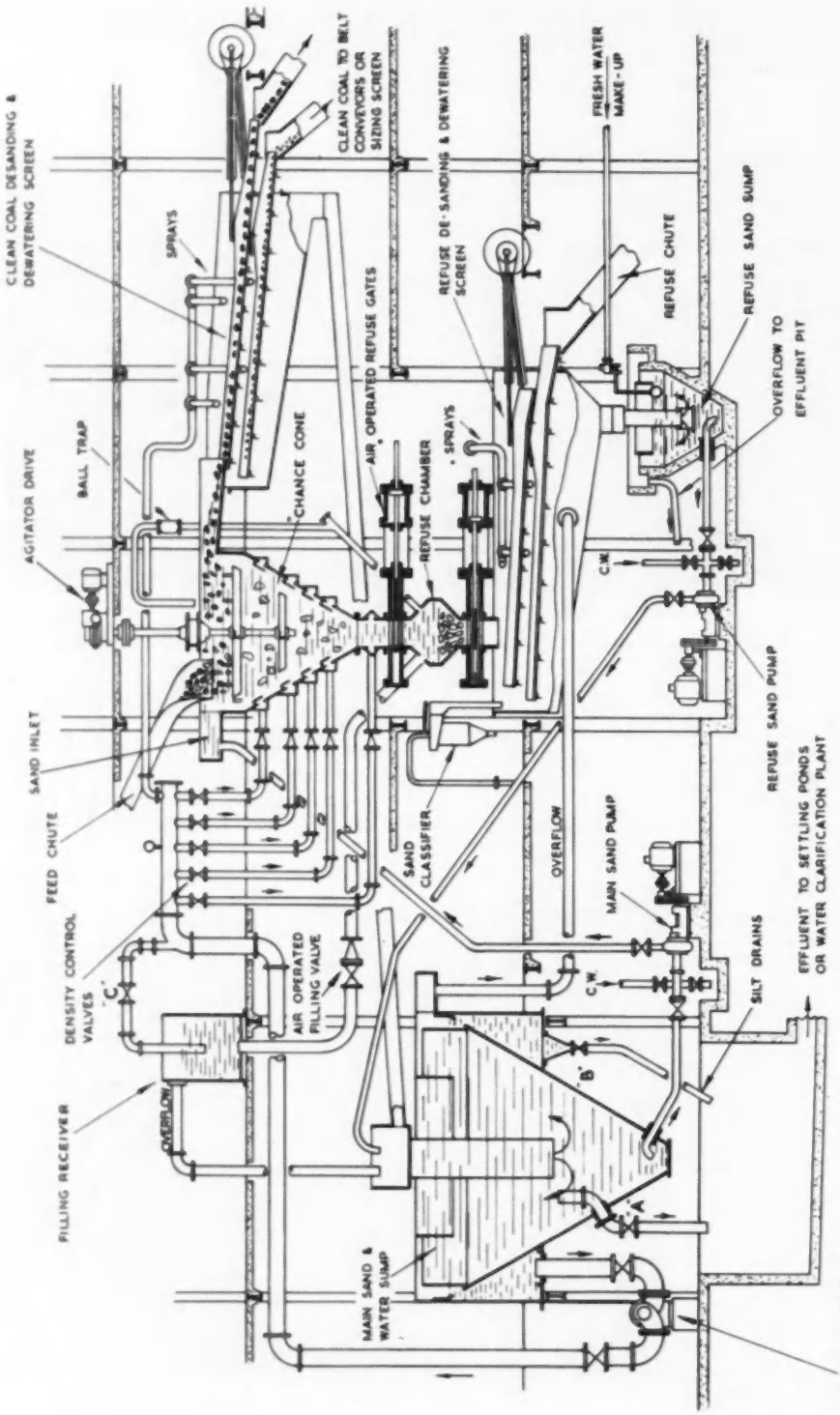

Fig. 5.—Pictorial arrangement of sand flotation process.

the 6 in. × 0 raw coal on to the primary raw coal screen, where it is separated with the aid of spray water into 6 in. × ½ in. and ½ in. × 0. The latter fraction is laundered with the aid of the spray water added on the primary raw coal screen, to two Sherwen high-speed electro-magnetically vibrated screens (fig. 4) for further wet screening into ½ in. × ⅛ in. × ⅛ in. × 0. The 6 in. × ½ in. fraction is delivered directly into the Chance washing cone, together with the ½ in. × ⅛ in. fraction from the Sherwen screens, via conveyors *P* and *N*. All the spray water added on the primary and Sherwen screens which contains the ⅛ in. × 0 fraction flows on to two high-speed zimmer type screens for dewatering.

The Chance cone (fig. 5 and 7), which is 10 ft. 0 in. in diameter, has been designed for a single gravity separation with products of clean coal and refuse. Provision has been made for the cone to be converted to make a two-gravity separation for producing clean coal, middlings and refuse if required in future. The connection on the cone for the middlings column has been blanked-off for the time being, but the middlings column can be fitted in a very short time without structural alterations.

Refuse extracted from the Chance cone is desanded and dewatered on a shaker type screen and is delivered to a 20-ton capacity bunker for disposal, via conveyor *A* (fig. 6 and 11). Meanwhile, the clean coal is also

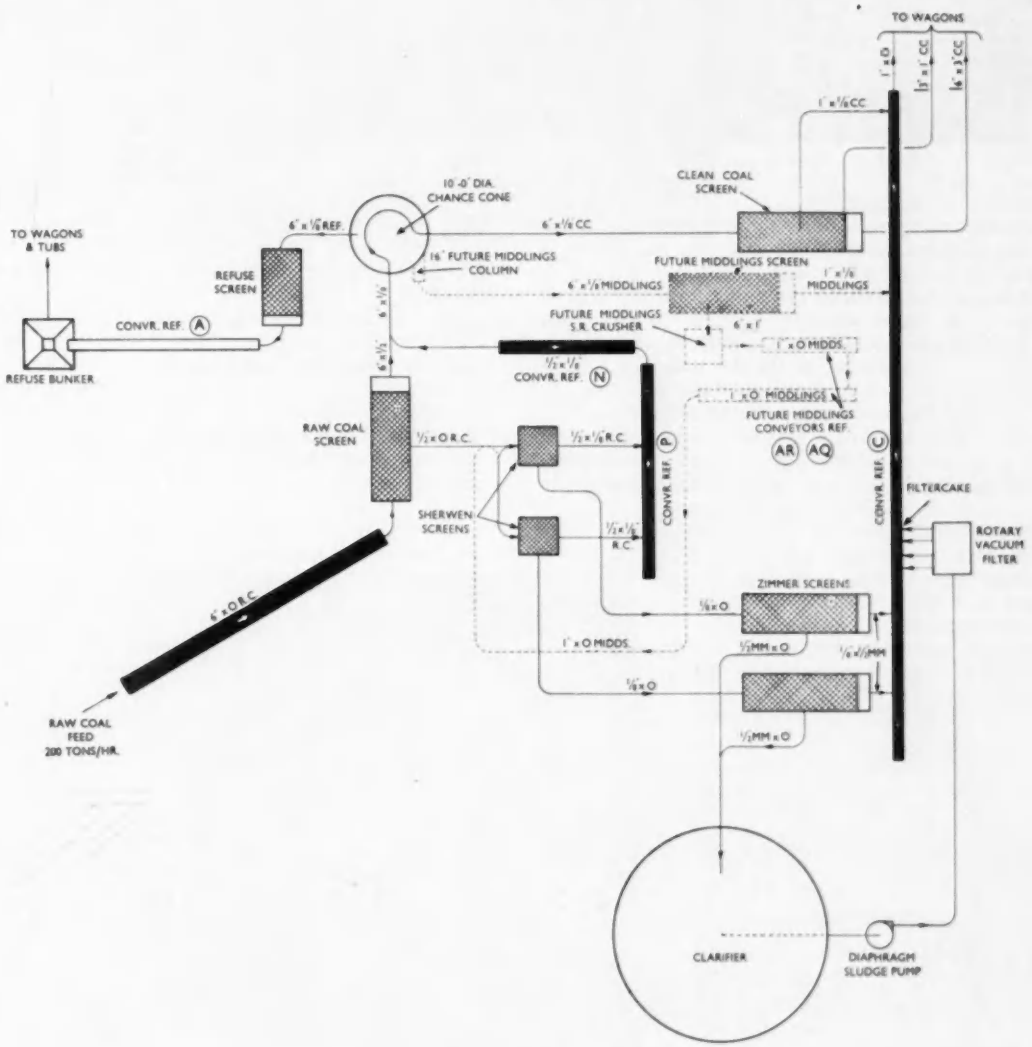

Fig. 6.—Coal flow diagram.

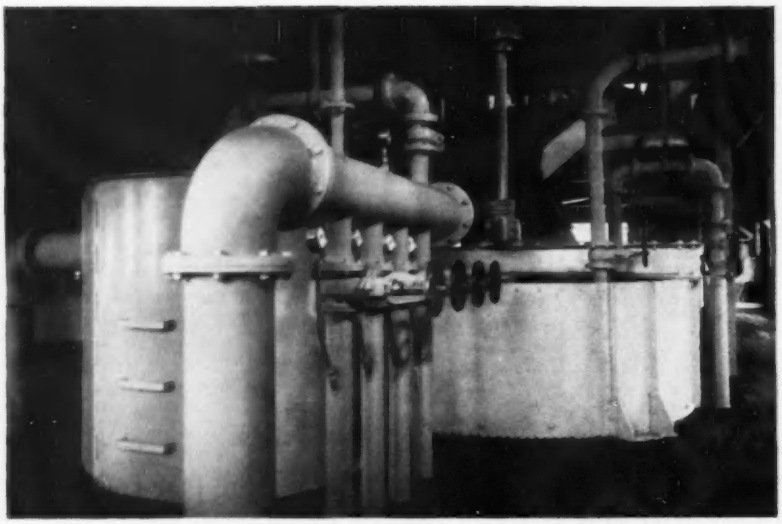

Fig. 7.—Chance cone with control valves in foreground.

desanded and dewatered on a shaker type screen which is also arranged to grade the coal into the following sizes: 6 in. × 3 in., 3 in. × 1 in., and 1 in. × ⅛ in. The first two sizes mentioned are loaded into rail wagons by means of chutes, while the latter size is discharged on to conveyor *C*, and then loaded to wagons.

The ⅛ in. × 0 fraction of the raw coal feed is laundered, together with all the spray water added on the primary and Sherwen screens, to the two zimmer type screens. Here the coal is dewatered and separated at a nominal size of ½ mm., the ⅛ in. × ½ mm. fraction being delivered to conveyor *C*, where it is joined by the 1 in. × ⅛ in. washed coal, in the manner already described. The water used for laundering, which now contains the ½ mm. × 0 fraction, passes to a 45 ft. diameter thickener for concentration. The clean water from the latter overflows into the clarified water sump for re-use in the washery circuit. The solids, which settle to the bottom of the tank, are fed towards the centre by means of a raking mechanism, and extracted by a positive head type diaphragm pump (fig. 9). The latter delivers the ½ mm. × 0 fraction, which is contained in approximately its own weight of water, to a bottom feed drum filter, 8 ft. diameter × 14 ft. long.

The drum speed is infinitely variable up to 2 r.p.m. and the drum is clad with a Monel metal cloth of 100 B.S. The filter reduces the moisture content of the ½ mm. × 0 coal to approximately 25 per cent., and the filter cake is then discharged on to conveyor *C* to join the ⅛ in. × ½ mm. dewatered coal and the 1 in. × ⅛ in. washed coal. The coal is remarkably free in filtering, and cakes as thick as 3 in. have been obtained, although 1 in. to 2 in. is more normal.

BELT CONVEYORS.

The belt conveyors throughout the plant are fitted with split roller bearings on all pulley shafts, while the idlers are Fraser & Chalmers-Robins three-pulley type, and fitted with taper roller bearings. The idlers are robust and ideally suited for the arduous duty of a coal preparation plant. Special attention has been given to the design of the seals, which are clearly visible in the idler cross section shown in fig. 10.

An additional feature of the belt conveyors, which contributes to the cleanliness of the plant, is the provision of spillage troughs under the return strands of the belting. These troughs, which can be seen clearly in fig. 12, are continually flushed with water, which is laundered to the zimmer screens, where the fine coal is recovered and the water returned to the system.

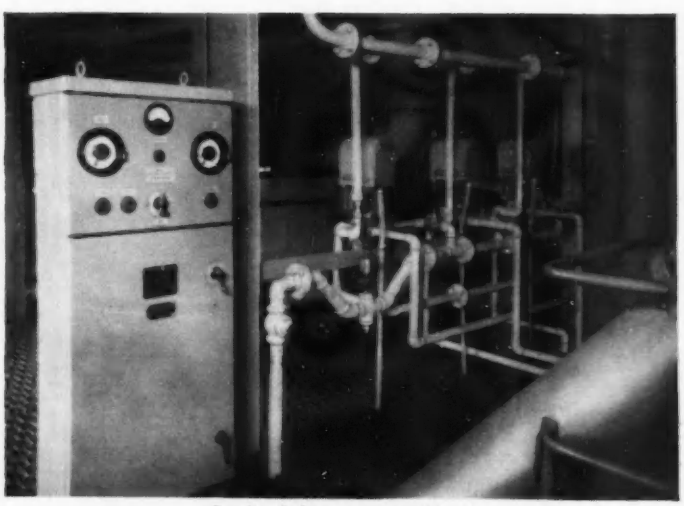

Fig. 8.—Refuse gate control panel.

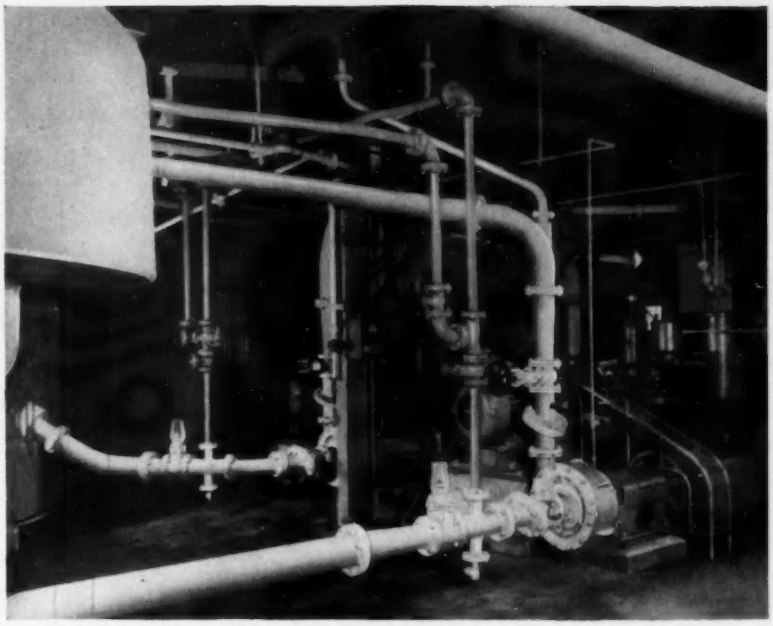

Fig. 9.—General view of pump basement.

stop the raw coal feed conveyor, in the event of a blockage occurring at any point in the system.

POWER WIRING AND LIGHTING.

Complete lighting and power wiring installation was included in the contract, together with a 500 kVA power transformer, manufactured in the British General Electric Company's E.P.M. Works. Power wiring was carried out in VIRLCSWA cable, and supported on suitable trays and brackets.

The lighting installation generally consists of steel reflectors with 500 W Osram lamps, except in tunnels, sumps, etc., where waterproof bulkhead fittings with 100 W lamps are provided. In addition, a number of 32-volt outlets was provided for hand inspection lamps, together with a number of 230-volt points for the operation of small power tools.

ELECTRICAL EQUIPMENT.

All driving motors are squirrel cage machines. They are totally enclosed, fan-cooled, dust- and weather-proof, and operate on a 415-volt, 3-phase, 50-cycle supply. Many of the drives in the plant are such that there is a high inertia on starting, and to obviate the use of slipring driving motors, with relatively more expensive and complicated control gear, traction-type fluid couplings have been fitted in these circumstances. The smooth starting conditions thus obtained reduce the wear on both the electrical and mechanical equipment. A typical drive incorporating this arrangement is shown in fig. 13.

Contactor type control gear, is arranged in groups around the plant, in positions, convenient to the various drives. A considerable proportion of the plant is sequence-interlocked, each starter in this category being fitted with an ammeter, sequence-test switch, "start" and "stop" push buttons, red "running-lamp" and amber "permit to start" lamp operated by the previous equipment in the sequence. Each drive is also provided with a "start" and a lock-in "emergency stop" push button adjacent to the motor. In addition, an emergency push button is provided on each floor of the plant to

BUILDING.

The washery building is of steel-frame construction, with roof and side sheeting of corrugated asbestos, and a number of opening windows for natural lighting.

The floors of the building are of the diamond-shaped grid type, which has a very pleasing appearance, and materially assists in ventilation and lighting. Bracing

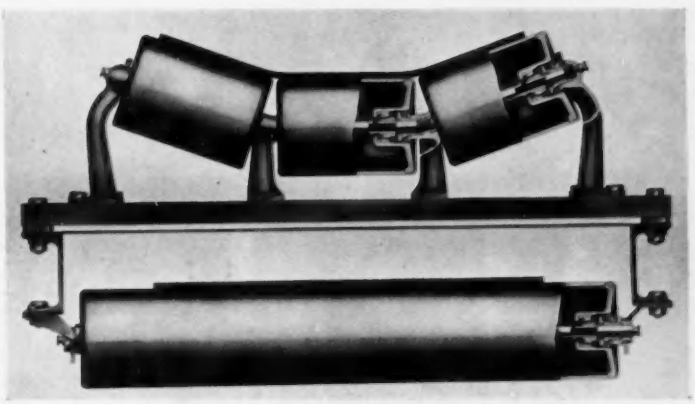

Fig. 10.—Sectional arrangement of Fraser & Chalmers-Robins roller bearing idler.

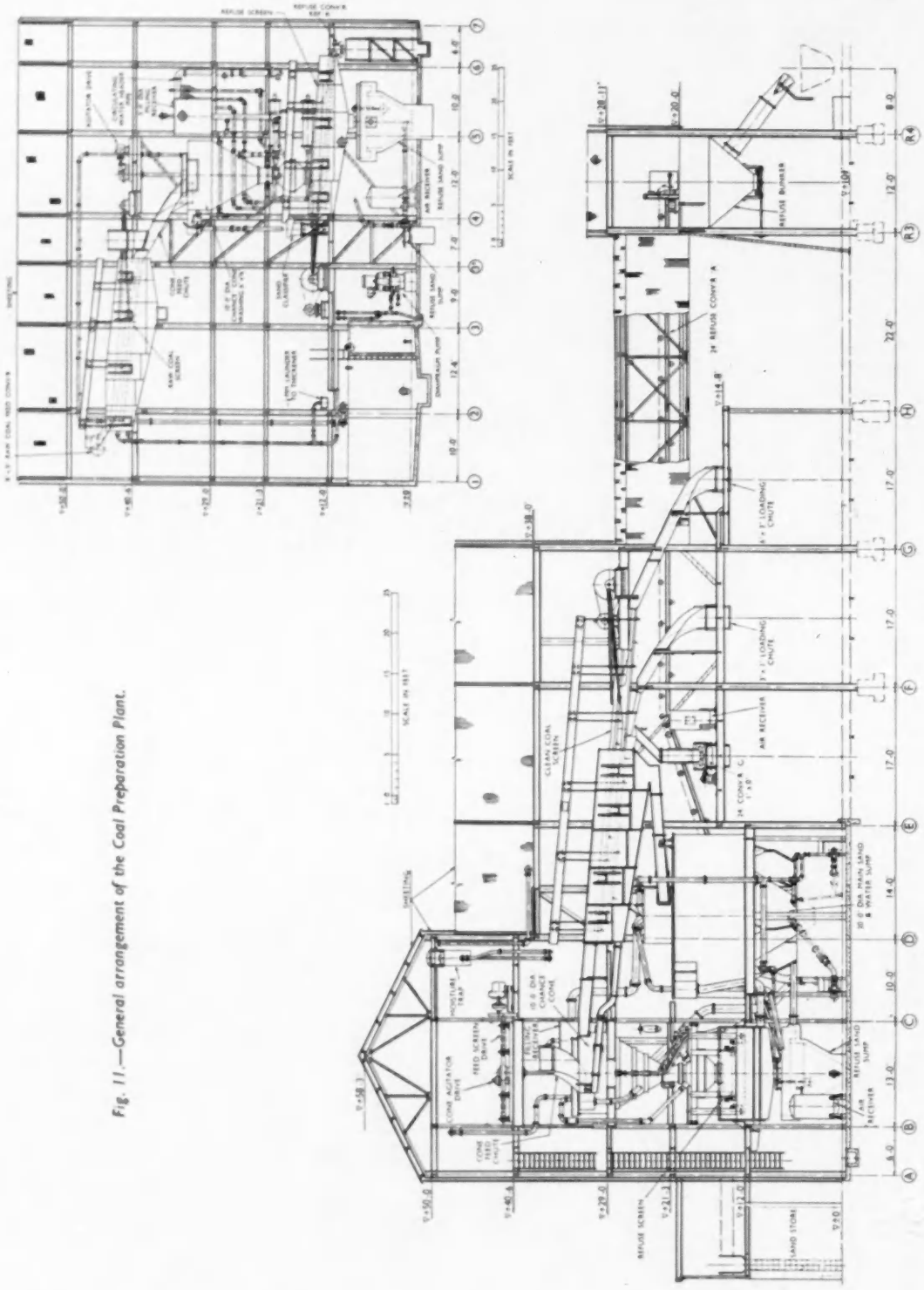

Fig. 11.—General arrangement of the Coal Preparation Plant.

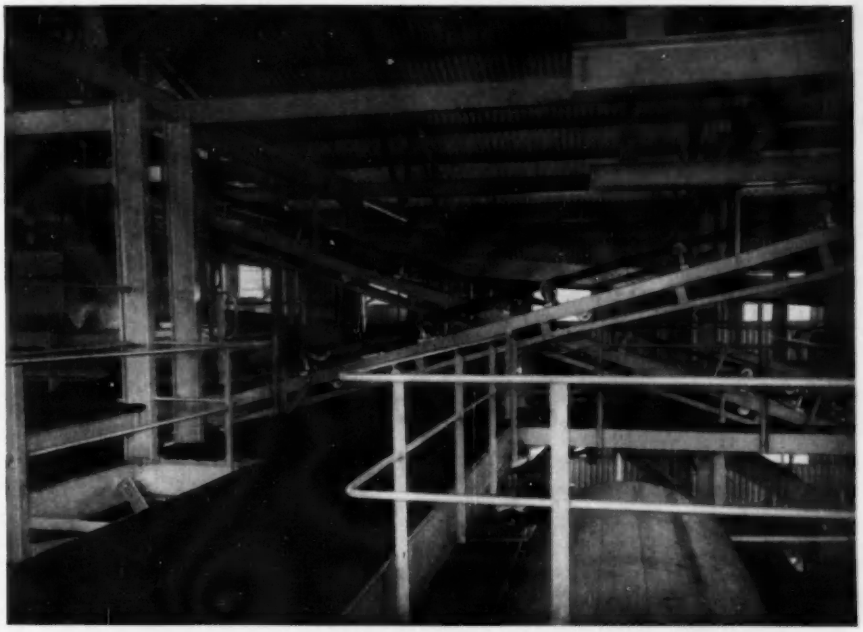

Fig. 12.—Interior view showing belt conveyors with spillage troughs.

is provided to resist the reciprocating loads imposed by the shaker-type screens. Stairways provide the access necessary for the operation of the plant.

The building was designed at the Fraser & Chalmers Engineering Works, and the detail drawings and fabrication were carried out in Australia.

FOUNDATIONS.

B.G.E.C. assumed complete responsibility for the whole of the washery foundations. In addition to the footings for the various building columns, this work covered the pits, sumps and tanks in the basement, and the foundations and trenches associated with the water clarification thickener tank.

PAINTING.

After erection, the equipment generally was painted battleship grey. A modern coal preparation plant

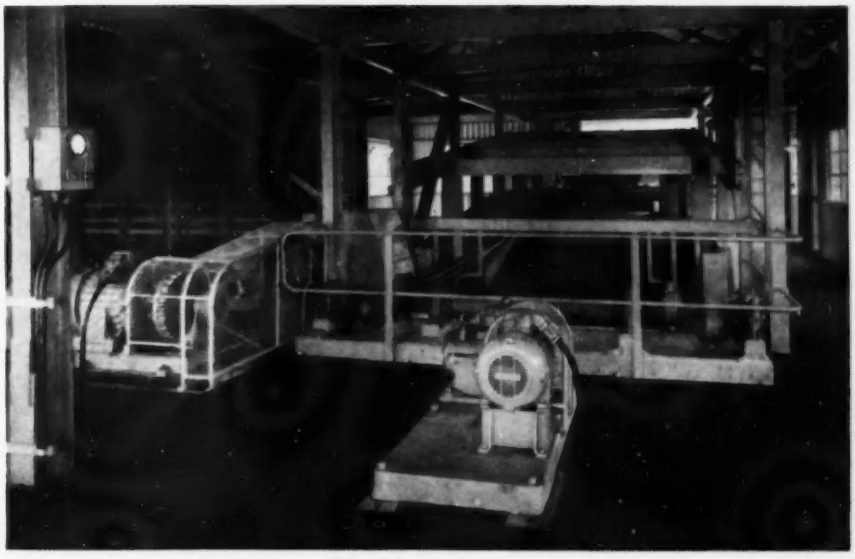

Fig. 13.—Primary raw coal screen showing vee-rope drive and fluid coupling.

incorporates a number of different water services, and in order to facilitate recognition the various pipelines have been painted in different colours, as follows :

Sand	Yellow
Fresh Water	Blue
Circulating Water	Red
Clarified Water	Brown
Effluent	Grey
Reagent	Black
Sludge	Dark Green
Filtrate	Sea Green
Air	Orange

This feature is of considerable assistance to the operators, and helps the rapid starting up of the plant.

SAND.

The medium used for obtaining a high density in the " Chance " cone is a mixture of silica-sand and water. The specification of the sand for use in the process is not rigid and a screening analysis is specified principally to enable a guarantee of consumption to be given. Sea or river sands, composed chiefly of quartz, are desirable, and fig. 14 gives the analysis of an ideal sand. Three other screening analyses of sands used at various plants are given, but it is quite permissible for the analysis to differ quite considerably from the standard. " Chance " plants have been installed all over the world, and in no case has there been any difficulty in obtaining a suitable, economic sand locally.

From the point of view of wear, it is preferable for the sand grains to be more or less round, as shown at *N* (fig. 14). However, the sections of the plant which come into contact with the sand are specially constructed so that even with a sand as shown at *M*, satisfactory results may be obtained.

Sand used at Corrimal, graph *C*, is readily obtainable from the seashore, about one mile from the plant. The sand is used as taken from the beach, and no preparation whatsoever is necessary prior to its introduction into the washery system.

REAGENTS.

Settlement of the ½ mm. ×0 raw coal in the thickener tank is assisted by the addition of suitable reagents. The raw coal feed at Corrimal is reasonably free from clay, and it has been found that filter alum and sodium aluminate are suitable for flocculation and give a satisfactory clarified water.

The mixing tank for the reagent is 3 ft. 4 in. in diameter by 5 ft. 3 in. high, and is fitted with a simple paddle-type agitator for mixing the reagents, which are supplied in powder form with water. Approximately 10 gal. of water are used to dissolve 100 lb. of alum into a concentrated solution, to which 10 lb. of sodium aluminate are added. When the latter is dissolved, water to make up to 250 gal. is added and the reagent is then ready for use.

After mixing, the reagent is pumped from the mixing tank to a suitable feeder for introduction into the

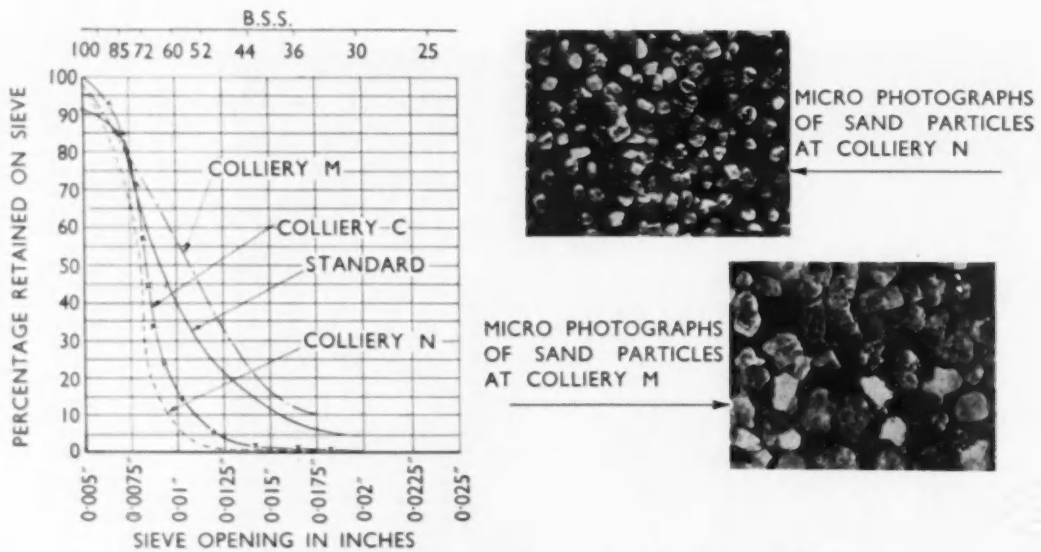

Fig. 14.—Sand-grading curves for use in the Chance process.

thickener feed launder. At the same time, a reagent storage tank is filled, which holds sufficient reserve of mixed reagent for feeding the system, during the time that a fresh batch of reagent is being mixed.

A solution in the ratio of 1 lb. of filter alum to 2.5 gal. of water, to which is then added $\frac{1}{10}$ lb. of sodium aluminate, has been found satisfactory. This solution is fed into the thickener feed at the rate of 45 gal. per hr. for every 10 t.p.h. of $\frac{1}{2}$ mm. $\times$ 0 raw coal delivered to the thickener tank.

Under these conditions, the plant has been able to operate with a closed water circuit, the only fresh water make-up required being that necessary to balance the moisture carried away with the washed products.

Sand is obtained and delivered to the plant at approximately 5*s.* (A) per ton, and the consumption is approximately $1\frac{1}{2}$ lb. per ton of raw coal delivered into the "Chance" cone. The latter amounts to an average of 165 t.p.h. in a total feed of raw coal of 200 t.p.h. of 6 in. $\times$ 0, so that the consumption of sand amounts to some 250 lb. per hr.

Full load power absorbed by the plant amounts to 195 kVA. This power is provided by generators running on waste heat from the Corrimal Coke Ovens and it is therefore difficult to obtain a true picture of power costs. For the purpose of calculating the cost of washing, however, it has been assumed that the cost of a kVA-hour is 2*d.*

Fig. 15.—General view of coal preparation plant with water clarifying equipment in foreground.

RUNNING COSTS.

The plant has not been in operation for a sufficient length of time to enable a true picture of the cost of washing the coal to be obtained. Certain costs are known, and it is possible to estimate others, in order to obtain a reasonable assessment of washing costs.

The design of the plant is extremely simple, and at the present time only three operators are actually employed on the plant, including the foreman.

On the basis that the plant would treat 350,000 tons per annum and assuming a 10 per cent. capital depreciation, the latter would amount to 12·5*d.* per ton of raw coal input.

As a reliable figure obviously cannot be obtained until the plant has been in operation for at least two years, it is necessary to make an assumption for repairs and renewals. A study of figures obtained from similar plants which have been in operation for some time, indicates that these costs amount to approximately 0·5*d.* per ton of raw coal.

Summarising, the following figures apply :

	Cost per ton input *d.* (A)
Labour	1·89
Sand	0·04
Reagents	0·50
Power	1·90
Capital depreciation	12·50
Repairs and renewals	0·50
	17·33

PRODUCTS.

Coal from the plant is used extensively for foundry coke making in " bee-hive " ovens. Also, due to the comparatively high fusion point of the inherent ash, the coal is an ideal one for steam raising.

RESULTS.

It has not been possible, as yet, to conduct a full-scale test on the products from the plant to determine its efficiency, although the coke obtained from the 1 in. × 0 size fraction is excellent, both from the point of view of ash content and structure.

The guarantees submitted stipulated that the washing errors on the 6 in. × $\frac{1}{8}$ in. fraction would not exceed the following :

Operating as a single gravity unit at 1.60 sg.
Sinks in Clean Coal 1.5 per cent
Floats in Refuse 1.5 per cent } on sample.

Preliminary tests which have been carried out indicate that the actual washing errors do not exceed those stated.

ACKNOWLEDGMENTS.

Acknowledgment is made to the principal sub-contractors as follows :

Fluidrive Ltd., Isleworth—Fluid couplings ;
Alfred Wiseman Ltd., Birmingham—Worm reduction gearboxes ;
A. S. MacDonald, Wagner & Priddle, Sydney—Civil Engineering Consultants ;
G. H. & H. A. Watsons Pty. Ltd., Sydney—Building Consultants ;
H. & E. Crossan, Pty. Ltd., Liverpool, N.S.W.—Steel-framed building chutes, hoppers, etc. ;
Duff & MacIntosh Pty. Ltd., Sydney—Thickener mechanism and vacuum filter ;
Electric Control & Engineering Limited, Sydney—Contractor control gear ;
H. R. Glossop Pty. Ltd., Wollongong, N.S.W.—Installation of power wiring and lighting ;
Taylor Woodrow (Aust.) Pty. Ltd., Sydney—Reinforced concrete foundations, etc.

Light in the Open Air

SUMMER holidays are followed all too soon by the comment that " the nights are drawing in ". To-day, however, the shorter evenings do not curtail outdoor activities and recreation to the same extent as they did in earlier years. Sport and spectacle continue under floodlights, and those who work out of doors enjoy the benefits of convenience and safety conferred by modern lighting installations.

Football probably has a larger following than any of the other sports which use this type of lighting. The names of many teams are household words, and matches played at Wembley Stadium command interest far outside the usual circles of enthusiasts (fig. 1). The Stadium has been equipped since last year with a floodlighting installation of unusual interest, the design of which typifies the detailed work which, unknown to the mass of spectators, is necessary in planning and carrying out such a scheme.

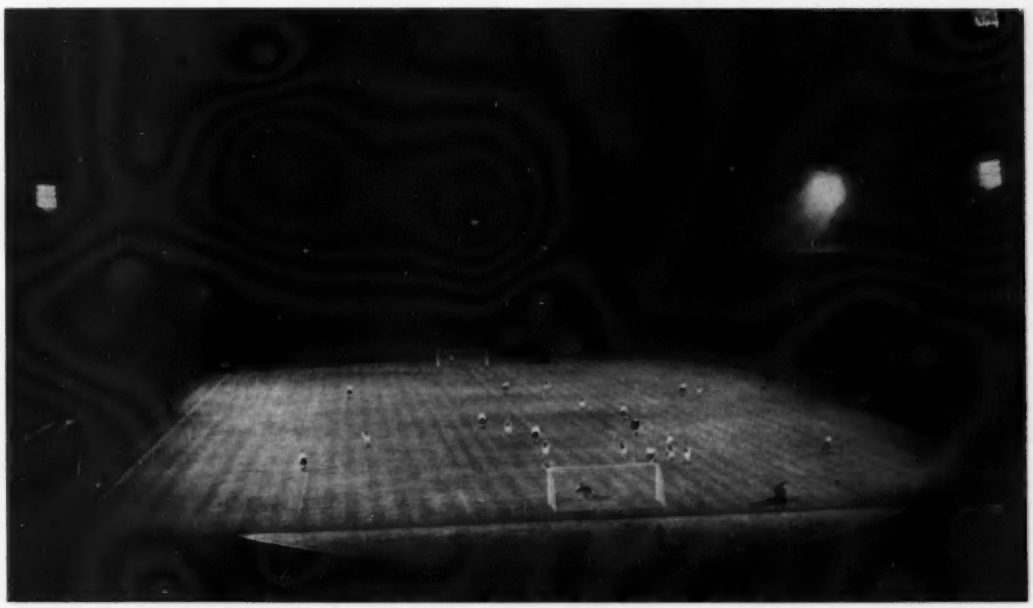

Fig. 1.—A match in progress under the floodlights at Wembley Stadium.

THE WEMBLEY SCHEME.

A scale model of the Wembley Stadium was built at the Research Laboratories, and hundreds of calculations were made in order to determine the correct type and combination of optical systems to employ. The group system of lighting was adopted, comprising 192 floodlights mounted 100 ft. above the ground in groups of 24 on 8 towers, and a combination of four optical systems was chosen. These are: (*a*) 60 narrow beam symmetrical optical systems using 1,500 W Osram projector lamps; (*b*) 72 medium angle and (*c*) 44 wide angle light distributions using Osram 1,500 W general lighting service lamps; and (*d*) sixteen wide-angle asymmetrical floodlights with 2 kW Osram horizon type line filament lamps, installed on each of the two central towers, and trained so as to give a high standard of illumination on players at the far side of the ground, but cut off sharply to prevent glare in the eyes of spectators on the terraces opposite.

The system is flexible, and the floodlights can be trained to give any distribution of light which might be suitable for events other than football matches. On numerous occasions lights have been brought

Fig. 2.—Standards and fittings for running track lighting at Tooting Bec.

into use in varying combinations to assist play on dull days.

DRAMATIC EFFECTS.

A special feature of the Wembley installation is the dramatic effect obtained by the provision of resistors in each of the four main feeders, each of which supplies two groups of floodlights. Before play begins, and during half-time, the resistors are in series with all the lamps and the effective voltage across the lamps is reduced from 210 volts to 185 volts. By the use of contactors and remote control switches, the resistors are shorted out and the illumination is raised to full brightness immediately the players enter the stadium. This arrangement also has the practical advantage of pre-heating the lamp filaments with a consequent safeguard of lamp life.

TENNIS LIGHTING.

The possibilities of floodlighting for amateur sports clubs are also of interest. Tennis clubs which have floodlit courts are finding that night play is becoming popular (fig. 3) and that there are more occasions on which it can be enjoyed in this country than some pessimists would admit. Excellent results can be obtained by using a type of fitting which is made in large numbers for industrial purposes, and has the correct angle of side cut-off to prevent the server from seeing the filament of the lamp in the corner of the court to which he is serving. A typical single court may be lighted by ten 750 W or 1,000 W lamps in angle reflectors mounted at between 20 and 30 ft. on two rows of tubular steel poles, with five poles at each side of the court. Frequently the poles can be situated in the line of the boundary netting, which they help to support. Players who have experience of floodlighting conditions agree that once they have become used to them, the game is very attractive and seems faster.

ATHLETICS.

Amateur athletics is another field for the application of floodlighting, where it enables training to be continued during the winter months by the many participants who must necessarily train in their leisure hours after a full working day. The lighting problem here is similar to that on speedways and greyhound tracks, the requirement being to illuminate the track without causing glare to the spectators or the contestants themselves. The same type of fitting is used, consisting of a reflector designed to give a suitable cut-off both longitudinally and at right angles to the track. Installations can be carried out economically by using

Fig. 3.—Tennis by floodlight at the Wigmore Tennis Courts.

Fig. 4.—The floodlit castle at Leiria, Portugal.

tubular steel poles with the top section canted over to form a bracket with an overhang of 10 ft. and giving a fitting mounting height of 16 ft. For a quarter-mile track such as that at on Tooting Bec Common, London, illustrated by courtesy of the London County Council in fig. 2, 48 fittings are required at spacings of 24 or 25 ft. and giving a fitting mounting height of 16 ft. Lamps for a lighting scheme of this nature may be 1,000 W or 750 W general service types.

OUTDOOR SPECTACLE.

The tattoo or pageant is a descendant of the Elizabethan and Jacobean masque. While the public theatres performed in the London daylight, which they transformed by verbal imagery into the sunshine of Venice or the gloom of the ramparts at Elsinore,

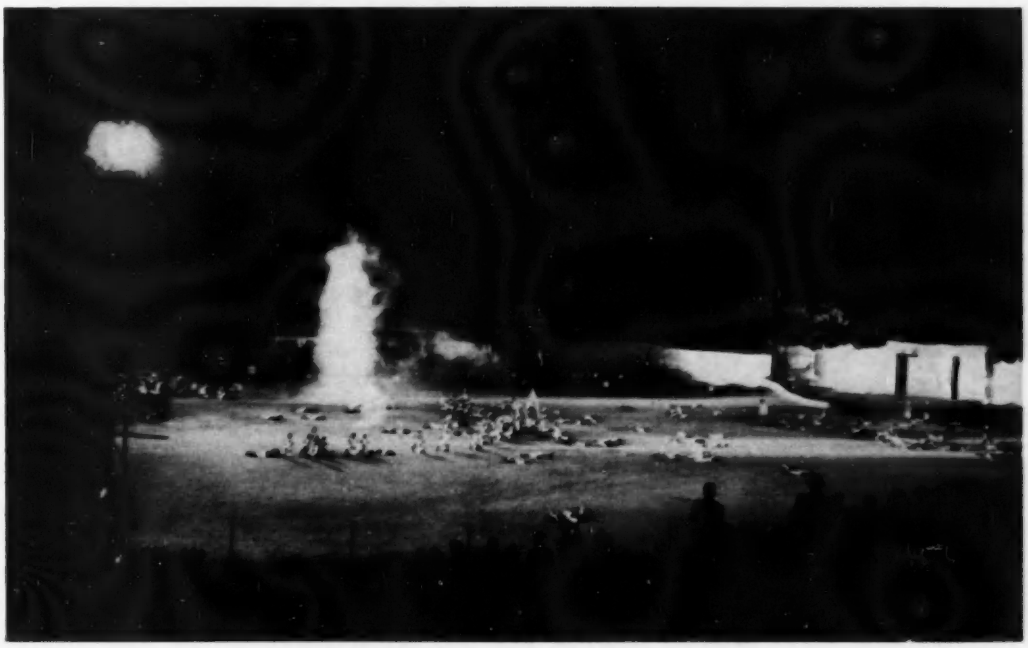

Fig. 5.—A battle scene in a floodlit military tattoo.

the producers of court entertainment were beginning to use light for light's sake. Francis Bacon, in his essay "Of Masques and Triumphs," wrote: "Let the scenes abound with light, specially coloured and varied", and proceeded later to enumerate the colours "that show best by candlelight". More than three hundred years later the lighting engineer erects his towers and floodlights to illumine the Battle of Corunna (fig. 5) or the Siege of Badajoz and uses discharge tubes with neon filling to simulate fire.

For a quieter evening's recreation, floodlighting beautifies parks and gardens and by the use of underwater units provides a range of colour effects for fountains, recalling again Bacon's description of them as "a great beauty and refreshment". Architecture (fig. 4) is dignified by the skilful balancing of light and shade. The modern tourist enjoys singular advantages in an after-dinner stroll to view "the memorials and things of fame that do renown this city".

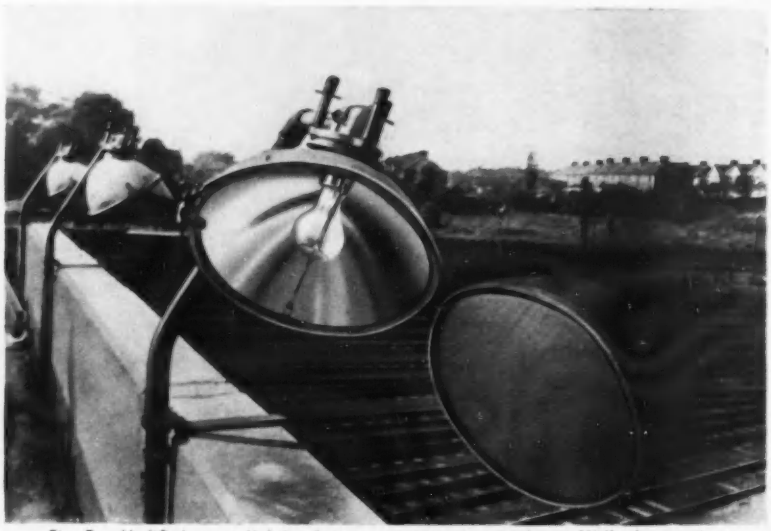

Fig. 7.—Modified street lighting lanterns on concrete gantries at Willesden carriage sidings, with one lantern swung inwards for maintenance.

LIGHT FOR INDUSTRY AND TRANSPORT.

Outdoor lighting of large open spaces for industry and transport takes innumerable forms and employs many types of lamps and equipment. In designing schemes for railway sidings the aim must be to avoid the use of poles between tracks as far as possible;

Fig. 6.—Sodium lighting in the sidings at Calverton Colliery.

this is accomplished in some installations by mounting floodlights on towers and in other circumstances by locating the lighting poles at each side of the sidings area. An example of sodium lanterns installed in this manner is shown in fig. 6. Another alternative, adopted in the extensive carriage sidings of the London Midland Region, British Railways, is the mounting of lanterns on concrete gantries spanning the tracks (fig. 7), the light sources in this instance being tungsten lamps in modified Uniway lanterns.

Airfield apron floodlighting is familiar to many travellers today, and in modified form airfield apron floodlights are often a satisfactory solution to problems encountered in dock and wharf lighting, where cut-off angles may have to be studied specially to prevent glare in crane drivers' cabins.

The Osram 1 kW mercury lamp, introduced specifically for high-bay interior lighting, also has its application to space lighting where large areas require illumination for night work. A steel billet yard illuminated by six of these lamps in area floodlights is shown in fig. 8.

Every aspect of space lighting touched upon in this short review is a study in itself. Collectively, all contribute to the enjoyment of leisure and the fruitful use of working hours which are essential to the balanced life of a modern industrial society.

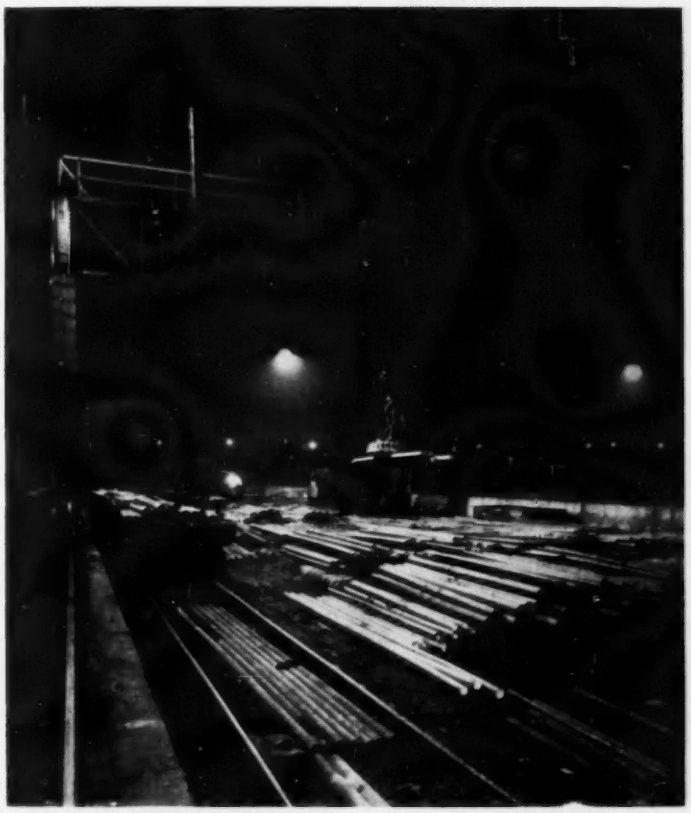

Fig. 8.—Osram 1 kW mercury lamps in the steel billet yard of Colvilles Ltd.

TECHNICAL LITERATURE

A digest of recent articles and papers, by members of the G.E.C. and its associated companies.

A HANDBOOK ON BELT CONVEYOR DESIGN.

Published by The Fraser & Chalmers Engineering Works of The General Electric Co. Ltd., 1956. *Price* 30*s*.

This publication is intended to be of service to all engineers engaged in the design and application of conveyor systems. It includes complete details of basic design. Variations of straightforward conveyor belts, such as conveyor type feeders, trippers and so on are dealt with at length; a chapter on Fundamental Analyses of Conveyors will be of great service to design offices.

A sample calculation for conveyors, with a description of how the details are worked out, forms the theme of the book. A series of tables and charts provides ready reference to all data required for conveyor calculations.

This publication will be of value not only to those engaged in conveyor design, but to students, trainees and to engineers contemplating a conveyor installation. While not claiming to be an unique reference work, the detail it contains is the outcome of half a century's design experience.

AN F.M. TUNER—THEORY AND CONSTRUCTION.

By E. Adler (Research Laboratories).

Norman Price (Publishers) Ltd., 1955. *Price* 5*s*.

This book presents in one small volume both the theoretical principles and constructional data to enable the home constructor to build an F.M. tuner suitable for feeding a high-quality amplifier.

The first part explains in simple terms the principles of amplitude and frequency modulation, and the advantages to be gained by the use of the latter. This is followed by a chapter on the ratio detector which deals with its theory of operation and the nature of its imperfections. Chapter 3 describes some aspects of receiver design.

The complete constructional details including the alignment procedure, power supply requirements and the connection of the tuner to the amplifier are contained in Part II. Optional additions to the basic design are indicated; these consist of automatic frequency control, the muting of inter-station noise, and tuning indication. The final chapter describes the construction of a suitable aerial.

ELECTRIC MULTIPLE-UNIT TRAINS AND EQUIPMENT.

By F. A. Manley (Traction Department).

Paper read at the Eighth British Electrical Power Convention, 1956.

The paper outlines the inherent advantages of multiple-unit trains and describes the various compositions of units. Examples are given of maximum and overall average speeds, including stops, attained by typical examples of modern equipment. The economic proportion of motored to non-motored axles in a multiple-unit train is considered, and present practice in motor suspension and insulation, and the trend towards weight reduction, are described. Later sections of the paper describe current-collection and control equipment, typical D.C. control schemes and alternative methods of control for 25kV, 50 c/s multiple-unit stock. The paper concludes with an account of auxiliary services and machines.

JUNCTION ADMITTANCE BETWEEN WAVEGUIDES OF ARBITRARY CROSS-SECTIONS (606).*

By E. D. Farmer (Research Laboratories).

Institution of Electrical Engineers Monograph No. 148*R*, *August*, 1955.

A general formula for the admittance of the junction between two waveguides of arbitrary and different cross-sections, coupled end-to-end by an aperture of arbitrary shape, is derived by the application of Schwinger's variational procedure. It is shown that, if the dominant modes of either waveguide have similar patterns over the coupling aperture, the junction may be represented approximately by a 2-terminal network. A eneral and simple definition of characteristic impedance is introduced which enables us to regard the junction as an "impedance mismatch" together with a "junction effect" owing to shunt susceptance. The restrictions required for an exact 2-terminal description are discussed. Simplified formulae, applicable when the waveguides have similar cross-sections, are derived. The symmetrical junction is also considered.

The approximate 2-terminal theory is applied to the junction between two rectangular guides of different E-plane dimensions and the results obtained are compared with those derived elsewhere by a more rigorous method. In this way some idea of the accuracy of the theory and the limits of its applicability is obtained. The 2-terminal theory is also applied to a circular-to-rectangular transition, and the results are shown to be in favourable agreement with experiment. The behaviour of a waveguide of hexagonal cross-section is analysed. Finally, various aspects of the impedance definitions are discussed.

SOME PROPERTIES OF MAGNETRONS USING SPATIAL-HARMONIC OPERATION (618).*

By R. G. Robertshaw and W. E. Willshaw (Research Laboratories).

Institution of Electrical Engineers Monograph No. 168*R*, *February*, 1956.

To reduce the problems involved in the design of magnetrons of low voltage and power for operation at frequencies of the order of 10,000 Mc/s and higher, a system is proposed in which the anode has only a few gaps, e.g. two or four. Operation at low anode voltage and magnetic field is achieved by electron interaction with the Fourier space components of the field.

A convenient and simple embodiment is described, and factors likely to result in operation different from the conventional multiple-circuit magnetrons are analysed briefly. In particular, the modes of oscillation and the magnitudes of the components of the different possible spatial harmonics are discussed for two types of anode circuit.

Details of operation of valves using both types of anode with two and four gaps are given, and comparisons are made where appropriate with the earlier analysis. The simple electrical structure of the two-gap anode enables a useful tuning range to be obtained by external-circuit adjustment, and some details of tuning performance are given.

The paper concludes with comments on noise performance and speed of build-up of oscillations.

INTERPRETATION OF WAVELENGTH MEASUREMENTS ON TAPE HELICES (622).*

By C. P. Allen and G. M. Clarke (Research Laboratories).

Institution of Electrical Engineers Monograph No. 151*R*, *October*, 1955.,

During the course of an investigation of helix propagation by the measurement of the standing-wave pattern in a shielded length of helical line open-circuited at one end, it was found that the minima of the pattern were not equally spaced when the phase-change per turn approached π radians, and furthermore, this phase-change remained nearly stationary at π radians over a finite frequency band. This would indicate a highly dispersive region which is not predicted by theoretical analyses.

However, when the results are interpreted, taking into account the presence of space harmonics, an explanation of the phenomenon is obtained which indicates that there will be a region of apparent dispersion for a finite length of helix, although the basic propagation on the infinite helix is dispersionless. Such an effect may be of importance in the operation of travelling-wave devices designed to operate through this band.

THE INFLUENCE OF PRESSURE ON METAL-GERMANIUM CONTACTS (625).*

By J. Lees and S. Walton (Research Laboratories).

Proceedings of the Physical Society, *B*, *Vol.* 68, *p.* 922, 1955.

The dependence of the electrical properties of the germanium immediately below a point contact on the stress existing in this region is investigated. Electrical and optical methods of measuring the area of these contacts gave different results. This anomaly is shown to arise from the variation of the resistance of the germanium with pressure.

A RADIO INTERFERENCE MEASURING SET USING POINT CONTACT TRANSISTORS (627).*

By J. N. Barry and G. W. Secker (Research Laboratories).

Electronic Engineering, *Vol.* 28, *No.* 336, *pp.* 53-57, *February*, 1956.

A portable battery-operated radio interference measuring set having a frequency range of 160 kc/s to 285 kc/s is described. This equipment is essentially a calibrated superheterodyne receiver having an intermediate frequency of 90kc/s and it incorporates a total of seven point contact transistors.

The minimum signal at the input terminals which can be measured reliably is 1μ volt in 75Ω or 15μ volts in 15 kΩ. The indicated output signal-to-noise ratio at these levels of input is 10dB. The power consumption is only 22 mA at 20 volts H.T., i.e. 440 mW total.

The instrument was designed primarily for the purpose of measuring those harmonic radiations from the line time-base of a television receiver which fall within the long-wave broadcast band. The set also has provision for monitoring, on headphones, any modulation output from a received signal.

ELECTROLUMINESCENCE (630).*

By J. N. Bowtell and H. C. Bate (Research Laboratories).

Transactions of the Illuminating Engineering Society, *Vol.* 20, *No.* 7, *pp.* 223-236, 1955.

This paper deals with the main features of electroluminescence and emphasises aspects of particular interest to illuminating engineers. Following a brief account of earlier work, the design, construction and performance of practical electroluminescent light sources are described. Essential theoretical aspects are also mentioned.

Certain specialised applications of electroluminescence for photographic and other purposes are discussed. Reference is also made to possible future uses for this light source.

TRANSISTOR POWER AMPLIFIERS (634).*

By R. A. Hilbourne and D. D. Jones (Research Laboratories).

Proc. I.E.E., *Vol.* 102, *Part B*, *pp.* 763-774, *No.* 6, 1955.

The factors governing the power-handling capabilities of *p-n-p* junction transistors in sinusoidal amplifiers are discussed. It is shown that, although the maximum allowed collector dissipation, $P_{c\,max}$, is an important transistor design criterion, it does not necessarily indicate the limit to the maximum output power possible; limitations set by other factors, notably the variation of current gain with emitter current, become particularly significant in Class B amplifiers because of their very high efficiencies.

The relative importance of Class A and Class B amplifiers is considered, and the three possible Class B push-pull arrangements are analysed in detail. It is shown that load-line techniques, such as are used in designing thermionic-valve power amplifiers, are not really suitable for transistors, and a different approach is made.

It is concluded that the common-collector Class B push-pull amplifier has a number of attractive features which favour its use. The design of a driver stage for this amplifier is described.

Complementary arrangements of *n-p-n* and *p-n-p* transistors are examined, but it is found that their advantages are not very great.

Finally, some non-sinusoidal power-amplifier applications are mentioned, and it is seen that transistors can be very important in this context.

THE HEATS OF FORMATION OF SOME TRANSITION METAL SILICIDES (635).*

By D. A. Robins and I. Jenkins (Research Laboratories).

Acta Metallurgica, *Vol.* 3, *No.* 6, *pp.* 598-604, *November*, 1955.

A method is described of determining the heats of formation of highly stable metal silicides and data are given for the following compounds: Ti_5Si_3, TiSi, $TiSi_2$, Zr_5Si_3, ZrSi, $ZrSi_2$, $ThSi_2$, V_2Si, Ta_5Si_3, $TaSi_2$, $MoSi_2$ and WSi_2. The highest heats of formation are those of compounds containing Group IVa metals and, in general, the disilicides are not as stable as compounds containing a lower percentage of silicon. An analysis of the bond lengths in the disilicides is carried out and a comparison is made between the heats of formation data and changes in the character of the metal bonding.

THE ECONOMIC ASPECTS OF ELECTRICITY FOR THE DOMESTIC HEATING LOAD.

By O. W. Humphreys (Research Laboratories).

Paper read at the Special Study of Domestic Heating, Institute of Fuel, May, 1956.

With the general raising of the standard of living in this country, increasing interest in the improvement of the present very low standards of domestic heating is to be expected. In the consideration of this problem economics must inevit-

ably play an important part. The paper is concerned with the economics of the use of electricity for domestic heating, but since economics are necessarily comparative the paper endeavours to show where electricity stands from the point of view of cost *vis-a-vis* alternative fuels as well as to give an indication of the absolute cost of heating electrically. The cost of a heating service varies widely according to what one expects of it. The paper therefore starts with a review of the relationship between comfort and environmental conditions; specifies a series of conditions which will yield varying degrees of comfort and discusses the quantities of heat required to maintain these conditions. The consideration of efficiencies of different types of heating equipment and systems yields the actual quantities of fuel required and, on the basis of assumed prices, the cost of providing the heating service. The data are so presented that relative costs can readily be determined for any combination of fuel, efficiency and fuel cost.

THE MEASUREMENT OF THE ELECTRICAL RESISTIVITY OF SILICON (648).*

By R. H. Creamer (Research Laboratories).

British Journal of Applied Physics, *Vol.* 7, *No.* 4, *pp.* 149-150, *April*, 1956.

A modified four-probe method is described which employs probes made from wires containing a donor or acceptor type impurity for *n*- or *p*-type silicon respectively. By discharging a condenser between the probes, low resistance stable contacts are obtained which allow a steady current to flow in the specimen and permit the potential to be measured with a standard potentiometer. Resistivity measurements by the normal method and by the four-probe method are compared; the latter measurements give an accuracy of about $\pm 7\%$ for resistivities up to several hundred ohm centimetres.

MULTIVIBRATOR CIRCUITS USING JUNCTION TRANSISTORS (649).*

By A. E. Jackets (Research Laboratories).

Electronic Engineering, *Vol.* 28, *No.* 339, *pp.* 184-189, *May*, 1956.

This article discusses the design and performance of low frequency free-running multivibrator circuits using junction transistors. The principles of operation are discussed; these include the condition for " bottoming ", factors determining frequency, and the sharpness of the output wave-form. Methods of varying the ratio of the ON to OFF periods are mentioned. G.E.C. EW53 *p-n-p* alloy type transistors are used throughout.

*** A limited number of reprints is available of those papers marked with an asterisk. Copies may be obtained on application to the Editor, G.E.C. Journal, Magnet House, Kingsway, W.C.2.**